FINAL PROJECT – TI141501

MEASURING MENTAL WORKLOAD OF AIR TRAFFIC CONTROLLER (ATC) BY USING DYNAMIC DENSITY (DD) AND NASA-TLX METHODS (CASE STUDY: AIRNAV INDONESIA SURABAYA BRANCH OFFICE)

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TUGAS AKHIR – TI141501

PENGUKURAN BEBAN KERJA MENTAL *AIR TRAFFIC CONTROLLER* (ATC) DENGAN MENGGUNAKAN METODE *DYNAMIC DENSITY* (DD) DAN NASA-TLX (STUDI KASUS: AIRNAV INDONESIA KANTOR CABANG SURABAYA)

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APPROVAL SHEET

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FINAL PROJECT

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ABSTRAK

Dewasa ini, permintaan pelayanan transportasi udara di Bandara Juanda bertumbuh sangat pesat. Untuk memastikan kualitas dan keamanan layanannya, salah satu aspek yang paling penting adalah kinerja *Air Traffic Controller* (ATC) di bawah manajemen AirNav Juanda. Kinerja tersebut bergantung pada keseimbangan beban kerja yang ATC rasakan. Oleh karenanya, pengukuran beban kerja ATC merupakan hal yang penting untuk dilakukan. Terutama untuk *Approach Unit (APP) Controller* yang memiliki banyak tuntutan tugas kognitif. Tugas tersebut antara lain mencegah tabrakan antar pesawat, melancarkan dan menjaga keteraturan arus lalu lintas udara, menyediakan saran serta informasi untuk penerbangan yang aman dan efisien, dan mengabari organisasi terkait pertolongan pada pesawat serta mendampinginya apabila dibutuhkan. Unit ini tidak hanya menangani pesawat yang menuju atau meninggalkan Bandara Juanda, namun juga pesawat yang melintas di sektor-sektor udaranya.

Salah satu metode objektif yang dapat merepresentasikan faktor kerumitan kognitif sebagai pemicu utama beban kerja mental APP *Controller* adalah *Dynamic Density* (DD). Dalam pengaplikasiannya di AirNav Juanda, DD didukung oleh sebuah metode subjektif yang telah banyak dipakai, yaitu NASA-TLX. Hal ini karena belum adanya metode pengukuran beban kerja mental secara objektif yang benar-benar mampu merepresentasikan beban kerja tersebut.

Hasil pengukuran faktor-faktor pemicu beban kerja mental APP *Controller* AirNav Juanda menggunakan DD didapatkan urutan 5 faktor kompleksitas lalu lintas udara tertinggi yaitu S5, NUMHORIZ, SCI, SV, dan disusul dengan C15. Kemudian berdasar pengukuran NASA-TLX, APP *Controller* yang merasa beban kerjanya ‘sangat tinggi’ ada 9.1%, ‘tinggi’ sebanyak 81.8%, dan ‘menengah tinggi’ sejumlah 9.1% dari 22 responden. Beban kerja tersebut dipicu oleh faktor-faktor kerumitan sebagaimana yang telah diukur menggunakan DD dengan R^2 sekitar 0.60497.

Kata Kunci: Beban Kerja, *Dynamic Density*, NASA-TLX, ATC, AirNav Juanda

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ABSTRACT

Today's growth of Juanda Airport air transport service is very rapid. To ensure the service quality and safety, one of most significance aspects is relied on ATC performance under AirNav Juanda management. This performance depends on appropriate workload burdened towards the ATC. Therefore, an ATC workload measurement is important to be conducted. Especially for Approach Unit (APP) Controller who has so many cognitive tasks. The tasks are prevent collision between aircrafts, expedite and maintain an orderly of air traffic flow, provide advice and information for the safe and efficient flight, and notify relevant organizations regarding aircraft in need of rescue and assist the mentioned organization if it is required. Moreover, this unit does not only handle departing and arriving flights, but also the passing through flights through its sectors.

One of objective methods which represent cognitive complexity factors that mainly trigger APP Controller mental workload is Dynamic Density (DD). In the application towards AirNav Juanda, DD is supported by a widely used subjective method, NASA-TLX. It is because there is still no objective mental workload which able to precisely represent the ATC level of workload.

Result of AirNav Juanda APP Controller mental workload triggering factors measurement by using DD shows top 5 weighting of the factors are S5, NUMHORIZ, SCI, SV and C15 respectively. Moreover, based on NASA-TLX assessment, 9.1% of 22 observed APP Controllers experience 'very high' category of mental workload, 81.8% 'high' and 9.1% 'medium high'. This workload is triggered by the complexity factors as measured by DD with result of R^2 for 0.60497.

Key Words: Workload, *Dynamic Density*, NASA-TLX, ATC, AirNav Juanda

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1. CHAPTER 1
INTRODUCTION

This chapter is purposed to introduce research initial stages. Introduction consists of background, problem formulation, objectives, benefits, research scope, and report outline.

1.1 Background

Air transport market competition becomes tighter and more demanded by rising of customer since 2000 in Indonesia (Bahrawi et al. 2007). It happens because of many private low cost carrier airlines were growing so thrive in Indonesia. Correspondingly, the demand of air transport service is also growing until now which is directly proportional to the increase of flight frequency that it has been recorded since 2006 until 2015. The Figure 1.1 shows the number of flight frequency which is increase significantly. This is a good news and challenge at once for the all aviation businesses because these are related elements which must be collaborated to ensure smoothness of every single flight in Indonesia.

Figure 1.1 The Number of Flight Frequency for the Last Ten Years Based on the Arrival and Departure of Domestic/International Flight in Indonesia
(Source: Central Bureau of Statistics (BPS), 2010 & 2016)

The most important factor to ensure sustainability of aviation industry is the assurance of good safety level (Suprasetyo, Head of Directorate General of Civil Aviation, 2016). In order to achieve it consistently, one of significant aspects in aviation sector is quality of Air Traffic Controller (ATC) performance. The ATC main tasks are controlling and guiding the air traffic under an authorized airspace which is technically called Flight Information Region (FIR) (AirNav Juanda SOP Manual Book, 2015). Obviously, the potential of air traffic accident rate depends on the performance of ATC. The better controller performance is the lower accidents rate will be.

A company which provides the air traffic service in Indonesia is a State Owned Enterprise named *Perusahaan Umum Lembaga Penyelenggara Navigasi Penerbangan* Indonesia (*Perum* LPPNPI) or commonly known as AirNav Indonesia (airnavindonesia.co.id, 2013). This company has responsibility to manage the air traffic in Indonesia since 16th January 2013 after separated from its initial companies, PT Angkasa Pura I and II. The air traffic in Indonesia was under PT Angkasa Pura I and II management before AirNav has been established on its own. AirNav Indonesia has several subsidiaries aside from its main office at Jl. Ir. H. Juanda No 1 Tangerang. One of AirNav branches supports Juanda International Airport of Surabaya (Juanda Airport) air traffic is AirNav Indonesia Surabaya Branch that is called AirNav Juanda.

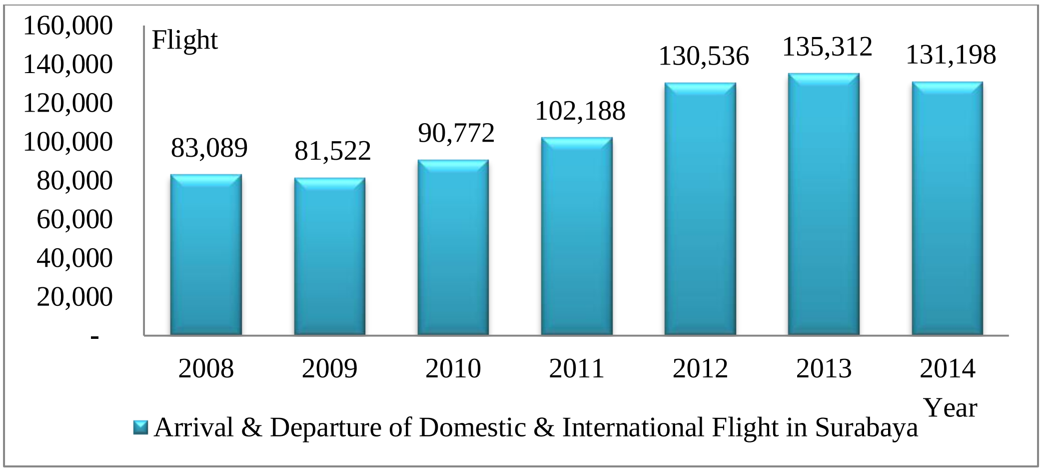

Figure 1.2 The Number of Flight Over Seven Years Based on the Arrival and Departure of Domestic/ International Flight in Indonesia
(Source: Surabaya Central Bureau of Statistics (BPS), 2014)

Juanda Airport is the second busiest airport in Indonesia which provides 132,907 flights annually in average based on data in 2011 until 2015 *(Statistik Lalu Lintas Angkatan Udara,* 2015). The number keeps rising until it reaches 8.4% in average per annual over seven years (start from 2008 until 2014 which is shown on the Figure 1.2); certainly, it will be keep rising in the future. In 2017, Juanda Airport operates two terminals which are named Terminal I and Terminal II for daily duty. Terminal I is responsible to maintain almost whole domestic flights. Meanwhile, all international and some domestic flights maintaining duty is taken by Terminal II.

ATC of AirNav Juanda is classified into two service areas based on its airspace altitude structure which are Juanda Tower Unit (TWR) and Juanda Approach Unit (APP) (airnavindonesia.co.id, 2013). ATC who is assigned for TWR is called as TWR Controller; and the call sign for ATC who has responsibility for APP is APP Controller. TWR Controller is assigned for zero to two thousand feet (0-2,000ft) of altitude; and then is continued by APP Controller within zero to twenty four thousand feet (0-24,500ft) that is wider controlling area. In this case, APP Controller has more complex task because on this altitude not only aircrafts which departed and landed in Juanda Airport; but also traffic of aircraft that passing through the authorized area must be handled.

Obviously, Juanda Airport is very busy refer to its traffic density and volume which are very high. These conditions are directly proportionate to workload experienced for the ATC. The conditions are coupled with an existence of inequality between numbers of worker needed to present. Based on a given formula within the Regulation of Directorate General of Civil Aviation Act No. 287 in 2015 (Act No. 287) related to calculation of the ATC number for a certain FIR, definitely, the APP Controller required is 81 persons. Actually, the APP Controller persons in AirNav Juanda are only 48 workers.

Indeed, the formula given in Act No. 287 is referred to Federal Aviation Administration (FAA) as well as the National Aeronautics and Space Administration (NASA) related to the ATC workload research and standards. To determine the appropriate number of ATC worker, this formula should consider the ATC level of workload based on the average number of aircraft service daily.

Currently in AirNav Juanda, the imbalance number of worker compared to the required one is consequently giving the workload of 81 APP Controllers (normally) to be burdened for the 48 people (Kuspitono, 2017). Whereas, the excessive workload would be triggering a decline of working performance because of stress, light to severe error and various short or long term healthy problems for the workers (Costa, 1995).

In order to measuring the ATC workload, recent studies show a method with the complexity consideration presents better R^2 of regression analysis rather than just aircraft count approach. The comparison is given on the Table 1.1. Therefore, the workload of APP Controllers must be assessed in more thorough way with consideration of AirNav Juanda airspace complexity. It is importantly to execute in order to define the level of workload the APP Controllers refer to their experiences to ensure the worker performance quality. By assessing each complexity factor of AirNav Juanda air traffic, some improvements plan could be focused on the several top significant factors and then the result of improvement plan application will be more measurable.

Table 1.1 R^2 Values of Complexity Approach Compared to Aircraft Count

Year	Model	Low Altitude Sectors	High Altitude Sectors	All Sectors
2009	Complexity	0.64	0.74	0.69
	Aircraft Count	0.50	0.44	0.46
2003	Complexity	0.40	0.37	0.32
	Aircraft Count	0.10	0.05	0.13

(Source: Kopardekar et al., 2009)

This research conducts the Juanda APP Controller level of workload by involving its complexity task into Dynamic Density (DD) calculation. This method is basically composed by three variables which are the traffic complexity factors (*TC*), the traffic density (*TD*) and the ATC intent (*CI*). These three main factors have been developed and formed as one combination of significant factors analysis. This procedure is purposed to measure thoroughly the APP workload and then compare the result with a widely used subjective method (NASA-TLX) to graph the workload level pattern.

DD is a specific method to measure ATC workload under complexity representation refers to the highest value of R^2 compared to other current studies. This method has been approved by many previous researches to express the complexity aspects that directly affect to the workload of ATC better than other objective methods. This method is also more objective and covers multidimensional aspects at once. Therefore, the workload measurement using DD can discover the detail of workload affecting factors, moreover each factor portion. Hereafter, the improvement plan could be applied effectively.

1.2 Problem Formulation

Based on the background, this research attempts to measure workload of AirNav Juanda APP Controller. Then apply DD towards Juanda APP Controller and suggest some improvements planning to reduce APP Controller workload by considering dominant complexity factor.

1.3 Research Objectives

This research is intrigued by several objectives. The objectives are generated as follow:

- To measure complexity factors portion in Juanda air traffic which affecting the APP Controller workload.
- To measure AirNav Juanda APP Controller workload by considering traffic complexity factors.
- To analyze the DD result towards APP Controller of AirNav Juanda that will be supported by NASA-TLX.
- To propose the improvements planning in reducing the APP Controller workload that could be structured based on each factor priority level as well as each complexity factor is measured.

1.4 Research Benefits

The expected benefits which can be obtained from this research are given as follow:

- Company will know the triggering factors portion and level of its APP Controller workload.
- Company will able to prioritize the improvement plan to reduce the APP Controller workload.
- More concise DD factors considered for AirNav Juanda will be generated.

1.5 Research Scope

In order to keep the research focused, right on target, reliable and valid; some limitations and assumptions are specified in advance of the research.

1.5.1 Limitations

The limitations are specified here to make the research focused, right on target, and reliable. They are as mentioned below:

- Topic is focus on assessing workload of AirNav Juanda APP Controller.
- APP Controllers who are surveyed are workers with one year minimum experience or licensed as APP-Surveillance.
- Number of ATC needed by AirNav Juanda is only reliable with F Category of flights per day (201-500 flights per day).

1.5.2 Assumptions

Several assumptions need to be stated in advance to make this research reliable, as elaborated below:

- Every DD factor value calculation which divided by 0, the result is assumed as 0.
- Result of same method applied in different objects represents relatively same result on AirNav Juanda components.

1.6 Writing Systematic

A brief explanation of report outline is generated in the next page. It is purposed to present the big picture of this research.

- CHAPTER I: INTRODUCTION

  The first chapter covers background, problem formulation, objectives, benefits, scope and report outline of this research. This chapter is important to keep the research in line, focused and reliable.

- CHAPTER II: LITERATURE REVIEW

  To produce good result, this research needs some appropriate and supporting theories and methods. These methods include NASA-TLX and Dynamic Density (DD).

- CHAPTER III: RESEARCH METHODOLOGY

  In order to make this research structured by systematic process, this chapter contains several steps of this research writing. The processing steps are described in flowchart and then explained further.

- CHAPTER IV: DATA COLLECTION AND PROCESSING

  This chapter contains data of observation object and its processing due to appropriate methods. These data are collected from literatures, observation, historical data, survey and interview. Then the raw data collected are screened and formulated as main data that can be further processed by appropriate methods. Then the process and its result can be presented as well.

- CHAPTER V: ANALYSIS AND INTERPRETATION

  The results of processing the data in the previous chapter are analyzed and interpreted in this chapter. This phase is important as a stage which leads to this research's conclusions and suggestions that also will be useful for company, AirNav Juanda.

- CHAPTER VI: CONCLUSION AND RECOMMENDATION

The last chapter presents conclusions which are purposed to answer the research objectives. Recommendations for the research topic and further research are also provided in this chapter.

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2. CHAPTER II
LITERATURE REVIEW

Some theories and methods are really important to achieve these research's objectives and generate intended benefits. In order to support research comprehension, some related theories are briefly elaborated in this chapter. These are collected from reliable secondary resources. Furthermore, subjects related in this chapter are Air Traffic Controller (ATC), Directorate General of Civil Aviation Act No. 287 of 2015 (Act No. 287), ATC work stress, ATC workload and its measurement which consists of NASA-TLX and Dynamic Density (DD), Analytical Hierarchy Process (AHP) and previous researches.

2.1 Air Traffic Controller (ATC)

Air Traffic Controller, or commonly shorten as ATC, is a person in charge to do aircraft management activity regarding its take off, fly and land (Cambridge Dictionary, n.d.). In other reference, ATC is a person who provides operation service to promote the orderly, safe, and expeditious of air traffic under an appropriate authority (Aerofiles, n.d.).

ATC task is divided based on the class of sky or airspace handled. The classification of sky is separated by considering its altitude which classified as Control Zone (CTR), Terminal Maneuvering Area (TMA) and Control Area (CTA). This classification can be set in different name even detail of area based on the requirement of each air navigation area, usually triggered by the airspace size or volume. Sometime, the difference in naming also can be caused by different system or technology used such as difference naming between surveillance and non-surveillance air navigation service.

Every sky classification has different flight phase such as take-off, departure, cruising, arrival and landing. Controller of CTR unit mainly handles take-off and landing aircraft by using direct visual from airport tower, this unit controller also frequently communicates with controller of TMA to ensure the higher sky level availability and readiness. Controller in TMA who assigned in

Approach Unit (APP) handles departure and arrival flight regarding the assigned airport, therefore this unit controller also frequently communicates with Controller in CTR who assigned in Tower Unit (TWR). APP Controller also provides navigation service for passing-through flight beneath authorized TMA. Furthermore, the cruising phase of flight which needs higher level of sky is controlled by controller in CTA. CTA of each country usually centered into one or two and more, depends on the size of the country itself. TMA and CTA airspace are mostly controlled beneath surveillance control. The figure below is illustration of flight phase controlled under each ATC unit classification.

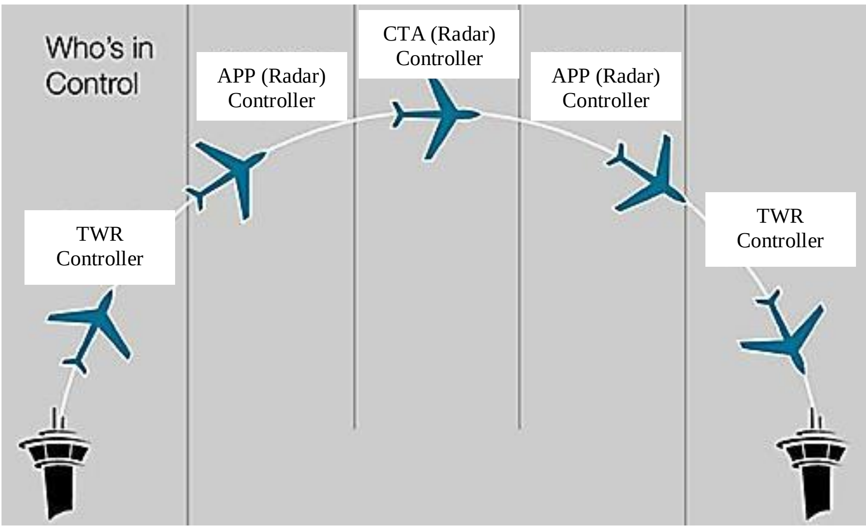

Figure 2.1 Illustration of ATC Task Classification based on the Airspace Altitude
(Source: atccareers.com, 2011)

2.1.1 ATC Classification in AirNav Juanda

ATC in AirNav Juanda is classified into two working unit based on their airspace altitudes which are Tower Unit (TWR) and Approach Unit (APP). TWR is separated into 2 sectors, which are Ground Sector and Tower Sector, with one supervisor to control all TWR Sector at once in one cycle. Total number of active ATC at TWR is 34 personnel. While, APP is divided into 3 sectors, which are Director Sector (Director) in control zone area, Terminal Maneuvering Area West Sector (TMAW) and TMA East (TMAE), with one supervisor for Director and one more supervisor for TMAW and TMAE at once. Total number of active ATC at APP is 48 personnel.

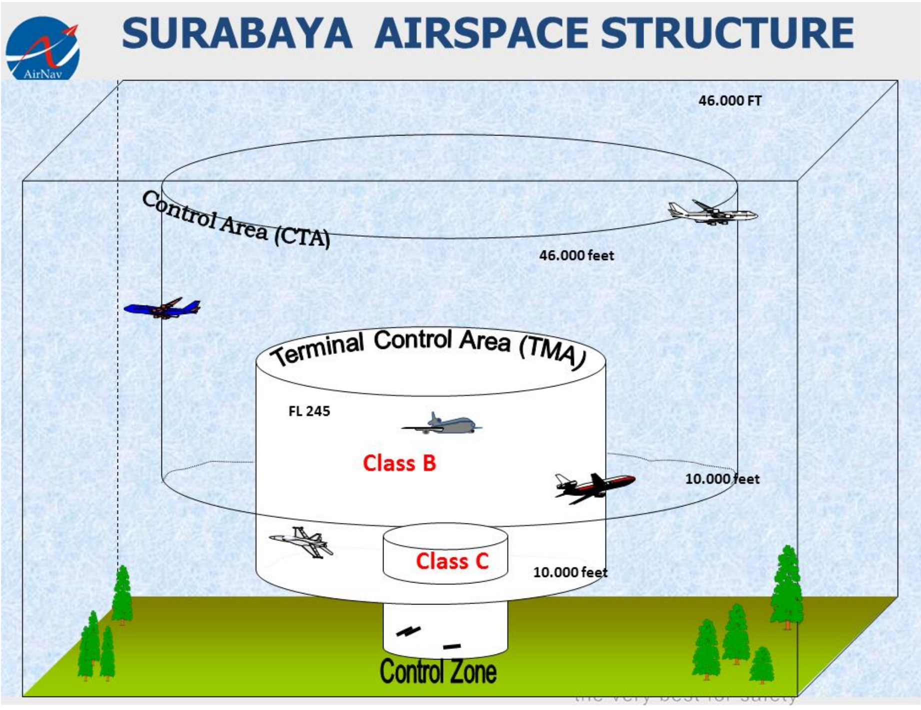

Figure 2.2 Rough Illustration of APP Sectors Airspace (White Cylinder) based on Altitude

(Source: ATC Performance Check, 2016)

Based on the altitude, working area of TWR Controller is 0-2,000ft and APP Controller is 0-24,500ft. TWR Controller is mainly purposed to handle aircraft in land; start from the aircraft is pushed back from apron, entering taxiway, take-off and landing in runway and parking in apron. While the APP Controller also has the same tasks as TWR Controller, except it not only manages flight leaving and directing from and to the airport, but also communicates with crossing aircraft in the higher altitude until 24,500ft. The task of APP Controller is more complex than TWR Controller because it handles more flight which is fully supported by surveillance tools. An APP Controller must has a minimum 5 year experience as TWR Controller and further training in order to to achieve Approach Control Surveillance Rating.

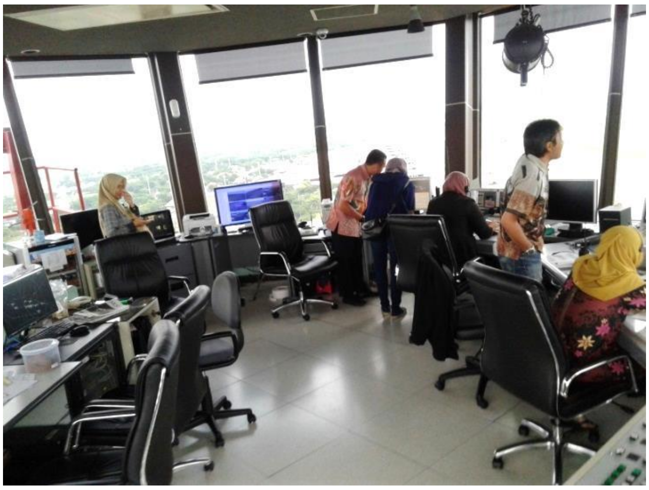

Figure 2.3 Work Station of TWR Controller

(Source: Private Document)

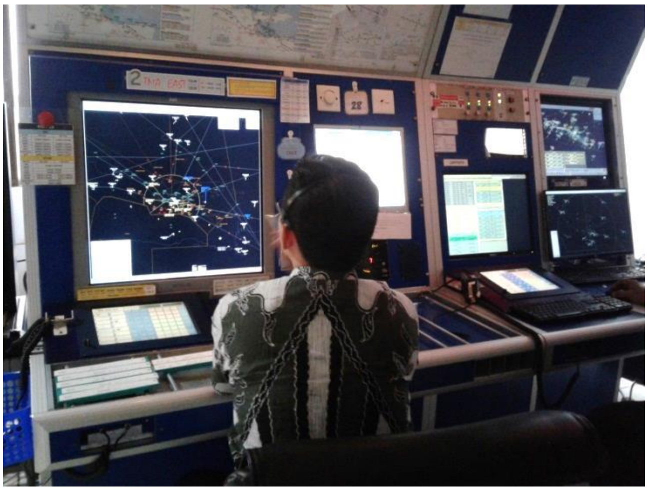

Figure 2.4 Work Station of APP Controller

(Source: Private Document)

APP Controller airspace traffic is separated into 3 sectors with 2 sectors in B Class Airspace and a sector in C Class Airspace. B Class Airspace is purposed to Instrument Flight Radar (IFR) and Visual Flight Rules (VFR), all flight is serviced and separated from each other. While C Class Airspace means to service between each IFR and VFR, with separated service between each IFR and VFR; the VFR flight is separated from IFR and receiving air traffic information which related to other VFR flight. The top view map of APP airspace area is attached on appendix 1 while the detail of it is generated on the table below,

Table 2.1 APP Controller Air Traffic Control Area

Director Sector			
Point	**S**	**E**	**Note**
1	07 40' 00"	112 56' 00"	All lower boundary is terrain
2	07 40' 00"	112 15' 00"	All upper boundary is 10,000ft
3	07 27' 00"	112 10' 00"	All Airspace Classification is Class C
4	07 25' 52.32"	112 06' 09.72"	
5	07 22' 26.18"	112 46' 16.39"	Thence an arc clock wise with a radius 40 NM centered at 'SSR' VOR/DME S5 and E5 to S6 and E6
6	07 49' 38.29"	113 15' 29.89"	
7	07 46' 00"	113 12' 00"	
8	07 40' 00"	112 56' 00"	
TMAW Sector			
Point	**S**	**E**	**Note**
9	04 57' 21.69"	112 47' 37.70"	All lower boundary is 10,000ft
10	04 57' 21.69"	113 58' 36.81"	All upper boundary is FL245
11	07 00' 40"	114 20' 04"	All Airspace Classification is Class B
12	07 27' 00"	114 25' 00"	
13	08 12' 00"	113 37' 00"	
14	07 49' 38.29"	113 15' 29.89"	
15	07 46' 00"	113 12' 00"	
16	07 40' 00"	112 56' 00"	
17	07 22' 26.18"	112 46' 16.39"	SBR' VOR/DME
18	04 57' 21.69"	112 47' 37.7"	
19	04 57' 21.69"	110 23' 00"	All lower boundary 10,000ft
20	04 57' 21.69"	112 47' 37.7"	All upper boundary is 24,500ft
21	07 22' 26.18"	112 46' 16.39"	SBR' VOR/DME

Table 2.1 APP Controller Air Traffic Control Area (Cont'd)

TMAW Sector			
22	07 40' 00"	112 56' 00"	All Airspace Classification is Class B
23	07 40' 00"	112 15' 00"	
24	07 27' 00"	112 10' 00"	
25	07 25' 52.32"	112 06' 09.72"	
26	07 13' 00"	111 23' 00"	
27	07 13' 00"	111 12' 00"	
28	07 22' 39"	111 03' 05.4"	Thence anticlockwise along the arc of circle radius 20 NM centered at 'SO' NDB to S28 and E28

(Source: AirNav Juanda SOP Manual Book, 2015)

Based on the air traffic working area, APP Controller is a person who assigned to provide air traffic control service including flight information and alerting service to arriving and departing controlled flight to and from area of AirNav Juanda. APP Controller main functions are listed below:

- Prevent collision between aircrafts
- Expedite and maintain an orderly of air traffic flow
- Provide advice and information for the safe and efficient flight
- Notify relevant organizations regarding aircraft in need of rescue and assist the mentioned organization if it is required

2.2 Directorate General of Civil Aviation Act No. 287 of 2015 (Act No. 287)

AirNav Indonesia is managed under Directorate General of Civil Aviation and been regulated under Act No. 287 of 2015 (Act No. 287). This regulation is purposed as advisory of ATC operational technique including rating license, training and capability of personnel. In order to ensure the ATC is well performed, any factors related working hours and capability are stated in Act No. 287.

2.2.1 ATC Maximum Working Hour Regulation

ATC working hour limitation and need of rest has been determined in Directorate General of Civil Aviation Act No. 287 of 2015 article 49 paragraph 1 to 3, the regulations of ATC working hour are assigned as follow:

1. ATC has to guide the traffic under authority comply with determined working hours.
2. Working hour for the controller is:
   a. Maximum total controlling hour in a week is 24 hours
   b. Maximum total controlling hour in a day is 6 hours, with maximum 2 hours continuously, and there must be a time lag of at least 1 hour break.
   c. Maximum total working hour in a day is 8 hours
   d. Maximum total working hour in a week 32 hours
3. Working hour for the controller assistant is:
   a. Maximum total controlling hour in a week is 24 hours
   b. Maximum total controlling hour in a day is 6 hours, with maximum 3 hours continuously, and there must be a time lag of at least 1 hour break.
   c. Maximum total working hour in a day is 8 hours
   d. Maximum total working hour in a week 32 hours

2.2.2 Formula to Calculate Number of ATC Needed

In purpose to standardize calculation of the number of ATC needed, Directorate General of Civil Aviation also regulate it in Act No. 287 article 49 paragraph 4 until 6. The regulations are as follow:

1. Calculation of number of personnel needed follows these categories as listed in table on the next page:

Table 2.2 Category of Air Traffic Provision Flight Service

Category	**Average Movement/day**
A	0-25
B	26-50
C	51-75
D	76-100
E	101-200
F	201-500
G	501-1,000
H	>1,000

(Source: AirNav Juanda SOP Manual Book, 2015)

2. Provision regarding number of operational personnel needed is in accordance with provision of working hours referred to paragraph (2) and (3) as well as the category referred to paragraph (4) with the formula of Number of Operational Personnel Needed,

$$Number\ of\ Operational\ Personnel\ Needed = \frac{Operating\ Hours\ x\ 365\ x\ number\ of\ CWP\ x\ number\ of\ sector}{Workload\ Category} \qquad (2.1)$$

Where: CWP = Controller Working Position/Sector

Workload Category is given in the table on the following page,

Table 2.3 Workload Category Air Traffic Provision Flight Service

Category	Workload Category
A	1,200
B	1,164
C	1,129.08
D	1,095.21
E	1,062.35
F	1,030.48
G	999.57
H	969.58

(Source: AirNav Juanda SOP Manual Book, 2015)

3. Provision regarding number of personnel supervisor is in accordance with number of working position and working shift with formula of Number of Supervisor Needed as follow,

$$Number\ of\ Supervisor\ Needed = 1.6\ x\ number\ of\ working\ position\ x\ number\ of\ working\ shift \quad (2.2)$$

2.3 ATC Work Stress

Based on aviation point of view, stress is a condition, or feeling, experienced when a person perceives that demands exceed the personal and social resources the individual is able to mobilize (SKYbrary, 2016). Since the ATC task is complex and demanding high responsibility, just like a flight crew who works in an intensive stressful environment, ATC is one of aviation professionals who face very high level of stress.

Referring to a research conducted by Professor Giovanni Costa (1995) which used by International Labor Organization (ILO) of United Nations (UN), “stress is not always bad because it is one of interaction effects between human and the environment…". It indicates that a person is doing activity and being productive. But stress may be harmful for health when it is perceived become excessive regarding individual ability to fulfill it. This effect can occur in a short time and long term period as imaged in the figure below,

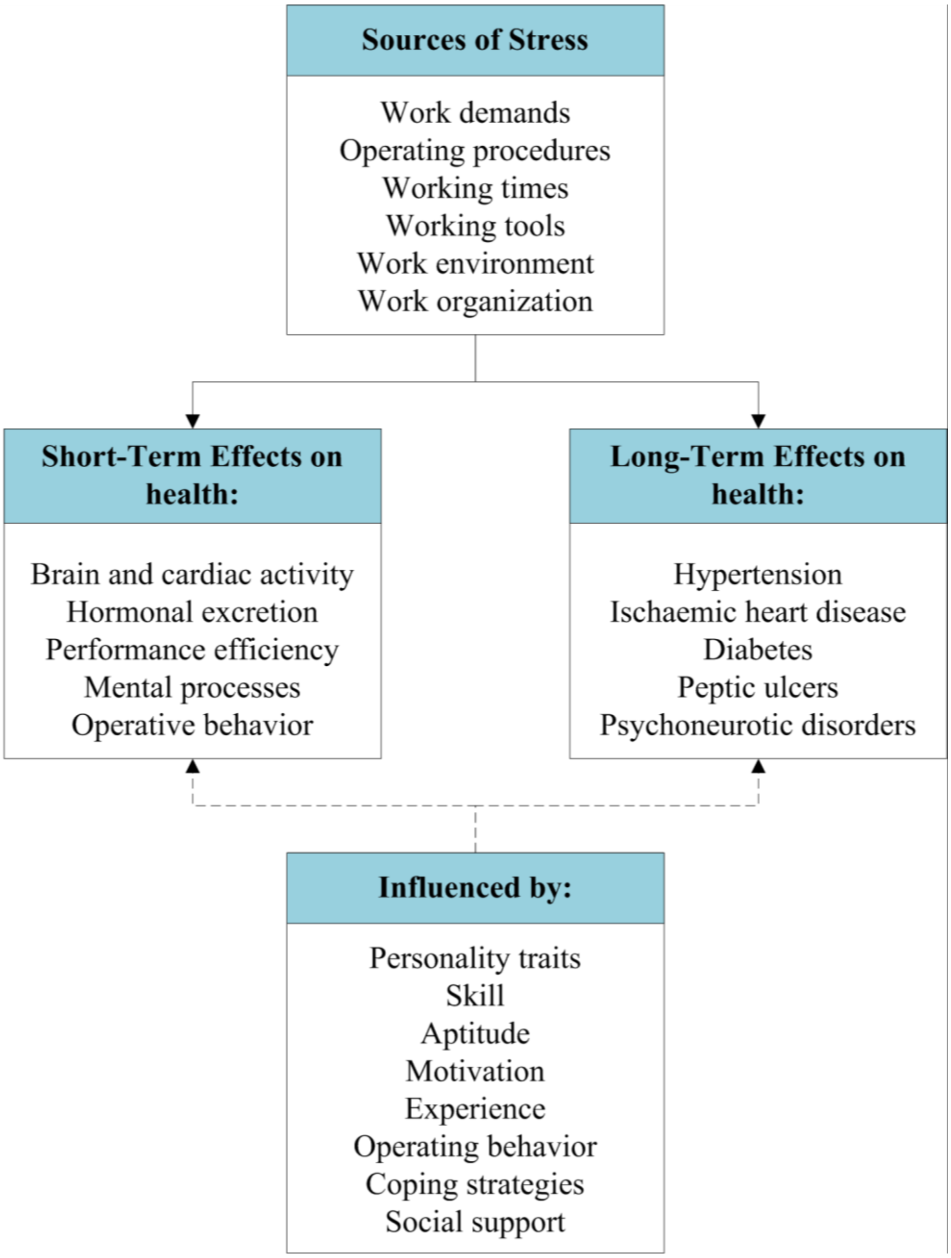

Figure 2.5 Main Consequences of ATC Stress

(Source: Costa, 1995)

Since the short and long-term effects of stress are significantly affecting the ATC performance and health factors, the balancing of ATC workload is important to be concerned. The work stress cannot be too low, neither high. Below is the figure of detailed potential work stress triggers which can be used as main consideration of stress management improvement.

Table 2.4 Main Sources of ATC Stress

Work demands	**Operating procedures**
Number of aircraft under control	Time pressure
Peak traffic hours	Having to bend the rules
Extraneous traffic	Feeling of loss of control
Unforeseeable events	Fear of consequences of error
Working times	**Working tools**
Unbroken duty period	Limitations and reliability of equipment
Shift and night work	VDT, R/T and telephone quality
	Equipment layout
Work environment	**Work organization**
Lighting, optical reflection	Role ambiguity
Noise/distracters	Relations with supervisors and colleagues
Microclimate	Lack of control over work process
Bad posture	Salary
Rest and canteen facilities	Public opinion

(Source: Costa, 1995)

2.4 ATC Workload

ATC has many structural, but dynamic, tasks in order to make the movement of air transportation smooth and safe. ATCs career is started from a discipline air traffic control school and then followed by very selective procedures. Many ATCs student even failed before graduate because they are seen as not qualified enough from the pupillage. After they are selected as one of professional ATCs, the tasks they have to deal with are very challenging and complex. Many cognitive tasks are critically needed in order to actively support the air traffic and keep in touch with pilots in purpose to liaison the plane on approach.

Move forward to workload definition, referring to Cambridge Dictionary (n.d), workload is an amount of work to be done, especially by a particular person. But the exact definition of workload is still debatable and really depended on the operational of the load itself, such as mechanisms, sources, consequences and measurement (Cain, 2007). Based on Hill Lysaght et al. (1989), workload aspects are mainly generated within three categories: 1) Amount of works and attributes to do; 2) unit of time consumed; and 3) operator's subjective psychological experiences.

For workload experienced by ATC, these three categories which composing the level of workload are integrated at once within a particular time. The workload is aligned with complexity and it is accumulated in a period of time; moreover, level of workload felt by the ATC really depends on the worker's experience or intent.

Cognitive complexity really defines the relationship between the ATC task to handle traffic and directly corresponding to mental workload. The ATC task mainly required cognitive effort rather than physical, so the mental workload can be considered as the ATC workload (Suárez, Lopez, Puntero, & Rodriguez, 2014). This research was proven in Indonesia by Urwatuz Zahara (2013) which shows that physical effort only constructing 4% of ATC workload.

2.5 Workload Measurement

Workload is defined as cost expended by an individual, by considering the worker capacity, in achieving a level of performance on a specific demand of task (Hart and Staveland, 1988). Workload is created from interaction between task demands, environments, and the skills, behaviors and perceptions of the individual person (DiDomenico and Nussbaum, 2008). Basically, workload is an opportunity to enhance working capability and experience of worker (Shah et al, 2011). But according to Robbins, 2009 in Shah 2011, inappropriate level of workload may trigger negative impact for the worker and also company. Too low workload may inflict lower working performance and productivity, meanwhile too heavy workload also has many negative impacts. The main negative impact of excessive workload is stress, this stress potentially triggers light until severe error and various short and long term health problems for the worker. Since appropriate and proportional workload is very important for the worker and company, workload assessment becomes critical thing that must be concerned.

Research about methods to measure workload has been established since many years ago and still become a hot issue in academic concern. It is because every work task is relatively different and specific regarding its working sector. Generally, workload measurement tools are concerned into two ways which are objective and subjective approach. Both of them are valid, but their accuracy depends on type of assessed workload.

Workload is classified into physical and mental workload. Physical workload is concerned in measurable portion in physical exposure of work which produces resource expenditure when performing a certain task (Gudipati and Pennathur, n.d.). On the other hand, mental workload is not exactly classified yet because it is an aggregation of multidimensional aspects which difficult to be defined (Cain, 2007). But, one definition of mental workload that commonly used which stated by Wilson and Eggemeier, 1991 in Cain 2007, “Mental workload refers to the portion of operator information processing capacity or resources that is actually required to meet system demands.”

Since workload is constructed from several unique factors, it is cannot be directly observed with a single universal workload measurement method (Cain, 2007). According to Gopher and Donchin, 1986 in Cain 2007, that is because there is no single representative workload that can be used in general purpose. Therefore, workload measurement method issue still becomes interesting topic and always developed time by time. From many researches, there are several methods to measure physical and mental workload as listed on the table 2.5 in the next page,

Table 2.5 Method to Measure Physical and Mental Workload

Physical Workload Measurement Tool	
Subjective Method	
Pain Estimation Charts - The McGaill Pain Questionnaire	
Armstrong et al. arranged some participants to rate grip force, tool mass and handle size based on their perception. It is scaled in continuous linear of "0 until 10" scale.	
Borg Rating and Perceived Exertion (RPE) Scale and Borg CR-10 Scale	
Body Diagrams - The Nordic Questionnaire	
	Objective Method
Energy Capacity by measure energy cost of performing an activity	Energy Cost
	Heart Rate
	Blood Pressure
	Blood Lactate Level
Biomechanical Analysis by evaluate stress on system of musculoskeletal	Stress on Musculosceletal System
	Stress on Lumbosacral Spine
	Biomechanical Design Criteria
Mental Workload Measurement Tool	
Subjective Method	
Subjective Workload Dominance (SWORD)	
Bedford	
Modified Cooper Harper (MCH)	
Psychophysical	
NASA-Task Load Index (NASA-TLX)	
Subjective Workload Assessment Techniques (SWAT)	
Workload Profile	
Objective Method	
Performance Measures	AGARD STRESS Battery
	Choice Reaction Time
	Criterion Task Set
	Multi-Attribute Task Battery

Table 2.5 Method to Measure Physical and Mental Workload (Cont'd)

Mental Workload Measurement Tool	
	Time Estimation/Interval Production
	Mental Arithmetic
Psychophysiological Measures	Heart rate measure
	Heart rate variability measure
	Measure of respiration
	Eye-blink activity measure
	Brain Activity measure
Analytical Measures	Task Analysis/Workload (TAWL)
	Time-Line Analysis and Prediction (TLAP)
	Workload Index (W/INDEX)
	Procedure Oriented Crew Model (PROCRU)
	Monitor Alert Parameter (MAP)
	Dynamic Density (DD)

(Source: Gudipati and Pennattur, n.d.)

Nature of jobs has been developed year by year with higher cognitive demand. It makes mental workload burdens higher than the physical workload. Whereas, physical workload is comparatively easier to be assessed than mental workload due to difficulty in defining mental workload and the availability of straightforward tests and measures (Tattersall et al., 1991). Therefore, the research about mental workload is still developed and becomes hot issue in industrial ergonomics.

2.5.1 NASA-TLX

National Aeronautics and Space Administration Task Load Index or generally known as NASA-TLX is a quantitative subjective workload measurement tool. This method is commonly used to measure cognitive or mental workload because it has relatively complete multidimensional assessment of factor affecting mental workload. NASA-TLX also covers measurement of physical factor effect regarding mental workload (Budiman et al., 2013).

Basically, a workload measurement method is chosen based on requirements which are generated by characteristic of the task. It is because there is no universal method which can be used for single particular type of task. In the ATC case, especially APP Controller, the task required multidimensional of cognitive and physical aspect at once. The APP Controller intends and subjected feeling can be represented in rating factors sheet, after that it is formulated into quantitative result to make it more measurable and reliable. The other decision variable in method selection is retrospectively horizon; since ATC workload is very affected by current condition, the workload measurement method which assesses current condition is more appropriate. Regarding the consideration of three selection variables, NASA-TLX is the most appropriate subjective rating method to measure APP Controller workload in AirNav Juanda. The comparison between NASA-TLX with the other methods is listed on the table 2.6.

Table 2.6 Comparison between Subjective Workload Measurement Method

Subjective Rating Method	**Unidimensional (U) Vs Multidimensional (M)**	**Absolute (A) Vs Relative (RL)**	**Immediate (I) Vs Retrospective (R)**
Bedford	U	A	I
MCH	U	A	I or R
Psychophysical	U	RL	R
SWORD	U	RL	R
NASA-TLX	M	A	I
SWAT	M	A	I
Workload Profile	M	A	R

(Source: Gudipati and Pennattur, n.d.)

As a multidimensional assessment method, NASA-TLX is designed to measure six dimensions of workload which are Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Own Performance (OP), Effort (EF) and Frustration (FR). This method consists of two measurement phases as follow:

1. Weighting : in this phase, respondents are asked to compare two 15 pairs of 6 dimensions. Number of tally given is performed as weight of every dimension.
2. Rating : in the second phase, respondents are asked to rate regarding the 6 dimensions of mental workload. Therefore, the last assessment of NASA-TLX mental workload measurement can be obtained by multiplying the dimensional weight with their respectively rating. After that, all the multiplication is summed then divided by 15. The result is defined as weighted workload (WWL) which classified into several level of workload category (Susetyo et al., 2012).

Table 2.7 Scale Rating of NASA-TLX

Scale	Rating	Information
Mental Demand (MD)	Low, High	Amount of mental activity and perceptual needed to see, remember and retrieve, simple or complex and loose or tight
Physical Demand (PD)	Low, High	Amount of physical activity needed (example: handling monitor panel, pull, push, etc.)
Temporal Demand (TD)	Low, High	Level of time pressure experienced within working element. Is the task demanded slowly and relax or quickly and exhausting
Own Performance (OP)	Inappropriate, Appropriate	How success the working performance of a worker and how he/her satisfied with the result
Effort (EF)	Low, High	How hard mental and physical work needed to solve a task or work
Frustration (FR)	Low, High	How unsafety, desperate, offended and disturbed; compared to safety, satisfied, comfortable and self-satisfaction feeling

(Source: Simanjuntak, 2010)

Table 2.8 Workload Category of Average WWL Value Result

No.	Average WWL Value Range	Workload Category
1	0-9	Low
2	10-29	Medium
3	30-49	Medium-High
4	50-79	High
5	80-100	Very High

(Source: Simanjuntak, 2010)

2.5.1.1 NASA-TLX Data Adequacy Test

In order to ensure the adequacy of NASA-TLX data, a data adequacy test is important to be conducted. Below are the formulas used to measure number of data needed based on determined confidence level and acceptable error standard (Wibisono, 2003).

$$\mu = \bar{x} \pm KS_{\bar{x}} \qquad (2.3)$$

Where:K is statistical value of t-distribution depends on intended level of confidence.

K for 95% level of confidence = 1.9645

With:

$$N' = \left(\frac{\frac{K}{s}\sqrt{N.\sum X_i^{\,2} - (\sum X_i)^2}}{\sum X_i} \right)^2 \qquad (2.4)$$

Where: N’ = amount of data needed

N = amount of data obtained

$S_{\bar{x}}$ = average estimation error standard

s = average sample error standard

X_i = observation data

2.5.2 Dynamic Density (DD) Model

There is no objective method which able to calculate the ATC workload accurately until 2015 (Dervic & Rank, 2015). It is because ATC workload is dynamic and each ATC has different difficulties and challenges among one and the others. Although the workload is relatively subjective, the importance of exact ATC workload calculation is getting higher because ATC working performance particularly influence the safety and quality of air transport which keep growing nowadays. This topic still becomes interesting issue and continuously developed by aviation researchers. Below is list of most commonly used ATC workload measurement methods and their comparison.

Table 2.9 ATC Workload Measurement Methods Comparison

ATC Workload Measurement Methods Comparison				**Note**	**Decision Variable Comparison**		
				(1)	**Unidimensional (U) Vs Multidimensional (M)**		
				(2)	**Absolute (A) Vs Relative (RL)**		
				(3)	**Immediate (I) Vs Retrospective (R)**		
No	**Year**	**Inventor**	**Method**	**(1)**	**(2)**	**(3)**	**Note**
1	1999	William J. Hughes Traffic Center (WJHTC), NASA and Metron Aviation	Dynamic Density (DD)	M	A	I	
2	2009	FAA	Monitor Alert Parameter (MAP)	M	RL	I	Purposed to calculate ATC sector capacity and congestion potential based on aircraft count approach. Then the result is used to represent ATC workload. Widely used in US, even worldwide

Table 2.9 ATC Workload Measurement Methods Comparison (Cont'd)

No	Year	Inventor	Method	(1)	(2)	(3)	Note
3	2009	FAA and NASA	Dynamic Density (DD)	M	A	I	Deeper research about DD presents more objective result than MAP (Kopardekar et al., 2009)

(Source: Kopardekar, 2009; Dervic and Rank, 2015)

MAP is relatively less objective than DD because the MAP values are generated by the facility that controls the sector and are not based on objective measures. Below is the comparison between regression output (R^2) of DD and MAP.

Table 2.10 R^2 Values of DD Metrics Comparison for Cleveland ARTCC

Year	Model	Low Altitude Sectors	High Altitude Sectors	All Sectors
2009	DD	0.64	0.74	0.69
	MAP	0.5	0.44	0.46
2003	DD	0.4	0.37	0.32
	MAP	0.1	0.05	0.13

(Source: Kopardekar et al., 2009)

Based on the initial inventor of DD, Laudeman et al. (1998), 'DD is a proposed concept of for a metric that includes both traffic density (a count of volume aircraft in volume of airspace) and traffic complexity (a measure of the complexity of the air traffic in a volume of airspace)'. This method is technically a weighted linear function method which is developed and validated through operational ATC. It becomes a greater opportunity to measure the workload experienced by related ATC and ability to redirect the incoming traffic better (Kopardekar et al., 2002). Therefore, DD is the most reliable method to measure ATC workload so far. The general DD formula is given below (Lauderman et al. 1998)

$$DD = \sum_{i=1}^{n} W_i \, TC_i + TD + CI \qquad (2.5)$$

Where: TC = traffic complexity factor

W = factor weighting

i = number of traffic complexity factor

TD = traffic density

CI = ATC intent

2.5.2.1 Development of DD Model

Since research about mental workload measurement method keep strived developed, so did the DD Model. This method was initially modeled by I. V. Laudeman and S. G. Shelden et al., under NASA Traffic Management Research in 1998. Start from this time, DD model keep developed by many aviation specialists. Below is the summary of DD model development:

- 1998 by I. V. Laudeman et al. and S. G. Shelden et al.

  Laudeman is a researcher from Ames Research Center California and S. G. Shelden et al. are researchers from San Jose State University California. They were collaborated under NASA Traffic Management Research and brought up a new ATC mental workload measurement method which considering traffic complexity, named Dynamic Density (DD). The participants of this research were ATCs from Oakland Air Route Traffic Control Center (ARTCC).

  From this research, DD basic model was put forward as the equation 2.3 by these researchers. They published 8 considered complexity factors which are given as follow:

  1. Heading Change (HC)
  2. Speed Change (SC)
  3. Altitude Change (AC)
  4. Minimum Distance 0-5 NM (MD 5)
  5. Minimum Distance 5-10 NM (MD 10)
  6. Conflict Predicted 0-25 NM (CP 25)
  7. Conflict Predicted 25-40 NM (CP 40)
  8. Conflict Predicted 40-70 NM (CP 70)

Therefore the generated basic formula of DD is given as equation 2.4,

$$DD = W_1(HC) + W_2(SC) + W_3(AC) + W_4(MD\ 5) + W_5(MD\ 10) + W_6(CP\ 25) + W_7(CP\ 40) + W_8(CP\ 70) + TD \quad (2.6)$$

- 2003 by Parimal Kopardekar and Sherri Magyarits

  Parimal Kopardekar as representation of NASA and FAA conducted a DD research with Sherri Magyarits from FAA. In this research, they modified and developed the 8 initial complexity factors into 4 DD metrics which are: 1) WJHTC Metric, 2) NASA Metric 1, 3) NASA Metric 2 and 4) Metron Aviation Metric. This result showed that DD has greater R^2 than method which only relies on aircraft count, their R^2 results were 0.23 and 0.69 respectively.
- 2009 by Parimal Kopardekar and Albert Schwartz et al.

  In 2009, Parimal Kopardekar from NASA Ames Center and Albert Schwartz et al. from FAA continued the previous research by creating an Additional Metric and then combining all the DD complexity metrics (as given in Table 2.12 until 2.17) to determine each factor significance using regression. The results of this research was 17 complexity factors were proven as significant and the regression of ATC mental workload measurement using these factors was 0.69, while an aircraft count method result for the same case was 0.46. This result also strengthened the initial belief and hypothesis that DD performs better ATC mental workload measurement than method which only relies on aircraft count.
- 2015 by Amina Dervic and Alexander Rank

  Amina Dervic and Alexander Rank were researchers from Department of Science and Technology Linköping University Sweden. This research mainly consisted of DD application using BEST RADAR simulator software toward Stockholm TMA to ease the detailed factor measurement. They made 20 scenarios to obtain ATC main response and work performance. The R2 of DD application was 0.58.

2.5.1.2 Calculation of Latest DD Model

In DD model, air traffic complexity is a collective effect of many factors which contribute to difficulty level of ATC to control the air traffic sector at any given time (Kopardekar et al., 2009). A regression comparison result shows that DD is reliable developed model and keep researched deeper. The regression with $\alpha = 0.05$ compares between DD research in 2003 and 2009 which turns the R^2 of regression result into much closer to 1 as given table below.

Table 2.11 R^2 Values of DD Metrics

Year	**Low Altitude Sectors**	**High Altitude Sectors**	**All Sectors**
2009	0.64	0.74	0.69
2003	0.4	0.37	0.32

(Source:Kopardekar et al., 2009)

Many researches try to specify appropriate composition of factors or variables which must be considered in air traffic complexity calculation. Therefore many standards of factor consideration are formulated as listed in the next page:

Table 2.12 WJHTC Metric Variables

WJHTC Metric	
Variable/factor	
Code	**Description**
AD1	Aircraft density 1 - number of aircraft divided by occupied volume of airspace
AD2	Aircraft density 2 - number of aircraft divided by sector volume
CRI	Convergence recognition index - measure of difficulty of detecting converging aircraft with shallow angles
SCI	Separation criticality index - proximity of conflicting aircraft with respect to their separation minima
DOFI	Degrees of freedom index - based on maneuver options in a conflict situation
CTI1	Coordination task load index 1 - based on aircraft distance from the sector boundary prior to hand-off

Table 2.12 WJHTC Metric Variables (Cont'd)

WJHTC Metric	
Variable/factor	
Code	**Description**
CTI2	Coordination task load index 2 - different formula based on the same principle as CTI1
SV	Sector volume
AC	Aircraft count

(Source: Kopardekar et al., 2009)

Table 2.13 NASA Metric 1 Variables

NASA Metric 1	
Variable/factor	
Code	**Description**
C1	Number of aircraft
C2	Number of climbing aircraft
C3	Number of cruising aircraft
C4	Number of descending aircraft
C5	Horizontal proximity metric 1
C6	Vertical proximity metric 1
C7	Horizontal proximity metric 2
C8	Vertical proximity metric 2
C9	Horizontal proximity metric 3
C10	Vertical proximity metric 3
C11	Time-to-go to conflict measure 1
C12	Time-to-go to conflict measure 2
C13	Time-to-go to conflict measure 3
C14	Variance of speed
C15	Ratio of standard deviation of speed to average speed
C16	Conflict resolution difficulty based on crossing angle

(Source: Kopardekar et al., 2009)

Table 2.14 NASA Metric 2 Variables

NASA Metric 2	
Variable/factor	
Code	**Description**
N	Traffic density
NH	Number of aircraft with heading change greater than 15°
NS	Number of aircraft with speed change greater than 10 knots or 0.02 Mach
NA	Number of aircraft with altitude change greater than 750 feet
S5	Number of aircraft with 3-D Euclidean distance greater between 0-5 NM excluding violations
S10	Number of aircraft with 3-D Euclidean distance between 5-10 NM excluding violations
S25	Number of aircraft with lateral distance between 0-25 NM and vertical separation less than 2000/1000 feet above/below 29000ft
S40	Number of aircraft with lateral distance between 25-40 NM and vertical separation less than 2000/1000 feet above/below 29000ft
S70	Number of aircraft with lateral distance between 40-70 NM and vertical separation less than 2000/1000 feet above/below 29000ft

(Source: Kopardekar et al., 2009)

Table 2.15 Metron Aviation Metric Variables

Metron Aviation Metric	
Variable/factor	
Code	**Description**
WACT	Aircraft count within a sector
WDEN	Aircraft count divided by the usable volume of sector airspace
WCLAP	Number of aircraft with predicted separation less than threshold value (e.g., 8 miles) at a particular time
WCONVANG	The angle of converge between aircraft in a conflict situation
WCONFLICTNBRS	Count of number of other aircraft in close proximity to a potential conflict situation (e.g., within 10 miles literally and 2000 feet vertically)

Table 2.15 Metron Aviation Metric Variables (Cont'd)

Metron Aviation Metric	
Variable/factor	
Code	**Description**
WCONF BOUND	Count of predicted conflicts within a threshold distance of a sector boundary (e.g., 40 NM)
WALC	Count of number of altitude changes above a threshold value with the sector
WHEADVAR	Count of number of bearing changes above a threshold value with the sector
WBPROX	Count of number aircraft within a threshold distance of a sector boundary (e.g., 40 NM)
WASP	The squared difference between the heading of each aircraft in a sector and the direction of the major axis of the sector, weighted by the sector aspect ratio

(Source: Kopardekar et al., 2009)

Table 2.16 Additional DD Metrics Variables

Additional DD Metrics	
Variable/factor	
Code	**Description**
NUMHORIZ	Number of aircraft with predicted horizontal separation under 8 NM
HDGVARI	Variance of all aircraft headings in a sector
AXISHDG	Squared difference between heading of each aircraft in a sector and direction of major axis
CONVCONF	Average angle of convergence between aircraft in a conflict situation
PROXCOUNT	Number of aircraft in close proximity to a potential conflict situation
ALTVAR	Variance and mean of all aircraft altitudes in a sector
NUMBNDY	Number of aircraft within a threshold distance of a sector boundary
ASPECT	Major axis length divided by minor axis length of a sector

(Source: Kopardekar et al., 2009)

Kopardekar et al. (2009) tried to measure significant level of each factor regarding its effect to complexity experienced by the ATC. Given that α equals to 0.05 and H_0 is the factor considered as not significant or not give effect to the complexity. The result of multiple regression equation is listed on the table in the next page,

Table 2.17 Multiple Regression Equation Result

Code	Description	Estimate	Std Error	t Ratio	Prob>|t|
Intercept		**1.204**	**0.233**	**5.16**	**<0.0001**
AD1	Aircraft density 1 - number of aircraft divided by occupied volume of airspace	14.132	4.978	2.84	0.0047
SCI	Separation criticality index - proximity of conflicting aircraft with respect to their separation minima	-0.007	0.003	-249	0.0129
SV	Sector volume	-0.0003	4.18E-05	-6.39	<0.0001
AC	Aircraft count	0.316	0.025	12.62	<0.0001
C2	Number of climbing aircraft	-0.517	0.137	-3.79	0.0002
C9	Horizontal proximity	-2.576	0.591	-4.36	<0.0001
C11	Time-to-go to conflict measure	-1.55	0.465	-3.34	0.0009
C15	Ratio of standard deviation of speed to average speed	-1.902	0.459	-4.14	<0.0001
C16	Conflict resolution difficulty based on crossing angle	3.658	1.49	2.45	0.0144

Table 2.17 Multiple Regression Equation Result

Code	Description	Estimate	Std Error	t Ratio	Prob>|t|
S5	Number of aircraft with 3-D Euclidean distance between 0-5 NM excluding violations	-0.406	0.115	-3.52	0.0005
S10	Number of aircraft with 3-D Euclidean distance between 5-10 NM excluding violations	-0.151	0.06	-2.51	0.0122
WCONV ANG	Angle of converge between aircraft in a conflict situation	0.651	0.125	5.2	<0.0001
WB PROX	Count of number aircraft within a threshold distance of a sector boundary (e.g., 20 NM)	-1.275	0.561	-2.27	0.0234
WASP	Squared difference between heading of each aircraft in a sector and direction of major axis of the sector, weighted by the sector aspect ratio	0.0261	0.002	10.69	<0.0001
NUMHO RIZ	Number of aircraft with predicted horizontal separation under 8 NM	0.446	0.081	5.49	<0.0001
HDG VARI	Variance of all aircraft headings in a sector	0.004	0.001	3.3	0.001
AXIS HDG	Squared difference between heading of each aircraft in a sector and direction of major axis	-3.01E-07	8.56E-08	-3.52	0.0005

(Source: Kopardekar et al., 2009)

Below is detailed information and formula about each factor listed on table 2.17 based on William S. Pawlak et al. (1996), Banavar Sridhar et al. (1998), Gano B. Chatterji and Banavar Sridhar (2001) and Parimal Kopardekar and Sherri Magyarits (2003):

$$AD1 = \frac{N}{airspace\ volume} \tag{2.7}$$

Where N is number of aircraft in a sector

(Kopardekar and Magyarits, 2003)

$$SCI = \sum (3 - SI)^2 \tag{2.8}$$

With condition that SI<3, SIV<2 and SIH<4

(Kopardekar and Magyarits, 2003)

$$SI = \frac{SIV + SIH}{2} \tag{2.9}$$

(Kopardekar and Magyarits, 2003)

$$SIV = \frac{\Delta h}{vertical\ minima} \tag{2.10}$$

Where vertical minima is 1000ft.

(Kopardekar and Magyarits, 2003)

$$SIH = \frac{\sqrt{\Delta X^2 + \Delta Y^2}}{lateral\ minima} \tag{2.11}$$

Where lateral minima is 15 NM.

(Kopardekar and Magyarits, 2003)

$$SV = sector\ volume\ (in\ NM^3) \tag{2.12}$$

(Kopardekar and Magyarits, 2003)

$$AC = N = number\ of\ aircraft\ in\ a\ sector \quad (2.13)$$

(Kopardekar and Magyarits, 2003)

$$C2 = \frac{number\ of\ climbing\ aircraft\ in\ a\ sector}{number\ of\ aircraft\ in\ a\ sector} \quad (2.14)$$

(Chatterji and Sridhar, 2001)

$$C9 = \frac{1}{\min\limits_{1 \le i \le N} \left\{ \min\limits_{j \in J_i} \{d_{ij}\} \right\}} \quad (2.15)$$

Where d_{ij} is distance between aircraft i and j

With condition that $J_i = \{j | h_i - \frac{\Delta h}{2} \le h_{ij} \le h_i + \frac{\Delta h}{2}; j \neq i\}$

Where Δh is altitude band in every 1000ft of altitude

(Chatterji and Sridhar, 2001)

$$C11 = \frac{\sum_{1 \le i \le N} \sum_{j \in T_i} 1}{2N} \quad (2.16)$$

With condition that $T_i \coloneqq \{j | 0 \le t_{ij} \le \Delta t; j \neq i\}$

(Chatterji and Sridhar, 2001)

$$C15 = \frac{\sigma_{vg}}{\bar{V}} \quad (2.17)$$

Where ${\sigma_{vg}}^2 = \frac{\sum_{1 \le i \le N} (V_i - \bar{V})^2}{(N-1)}$ while $V_i = \sqrt{{V_{xi}}^2 + {V_{yi}}^2 + {V_{hi}}^2}$ and $\bar{V} = \frac{\sum_{1 \le i \le N} V_i}{N}$

(Chatterji and Sridhar, 2001)

$$C16 = \frac{\sum_{1 \le i \le N} \sum_{j \in T_i} \omega_{\varepsilon_{ij}}}{2N} \quad (2.18)$$

With condition that the heading of the i aircraft is defined as $X_i = tan^{-1}\left(\frac{V_{yi}}{V_{xi}}\right)$

With condition that $T_i \coloneqq \{j | 0 \le t_{ij} \le \Delta t; j \neq i\}$

Where $\omega_{\varepsilon_{ij}} = min(|X_{ij}| 2\pi - |X_{ij}|)$ with following a normalized time for resolution initiation as given on the figure next page,

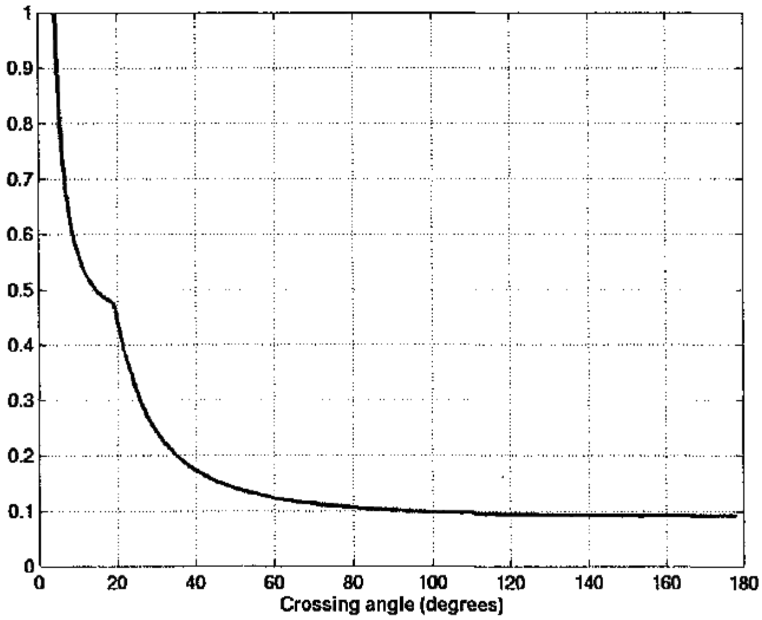

Figure 2.6 Normalized Time for Resolution Initiation
(Source: Chatterji, 2001)

(Chatterji and Sridhar, 2001)

$$S5 = Number\ of\ aircraft\ in\ a\ sector\ with$$
$$\sqrt{{d_{ij}}^2 + {h_{ij}}^2} \leq 5NM\ excluding\ violations \quad (2.19)$$

(Sridhar et al., 1998)

$$S10 = Number\ of\ aircraft\ in\ a\ sector\ with$$
$$5NM \leq \sqrt{{d_{ij}}^2 + {h_{ij}}^2} \leq 10NM\ excluding\ violations \quad (2.20)$$

(Sridhar et al., 1998)

$$NUMHORIZ = Number\ of\ aircraft\ in\ a\ sector\ with\ d_{ij} \leq 8NM \quad (2.21)$$

(Kopardekar 2009)

Significant level of regression on table 2.17 is measured by using basic regression formula mentioned in the next page,

$$y_i = a_i x_i + b \tag{2.22}$$

Where: y = complexity

a = 'estimate'

x = factor unit

b = 'intercept estimate'

(Kopardekar 2009)

In order to weight the complexity factor, some expert judgments must be collected, categorized, and weighted by using Analytical Hierarchy Process (AHP). AHP is one of Multi-Criteria Decision Making (MCDM) Methods which appropriate to solve complex problem with multiple conflicting and subjective criteria (Ishizaka and Labib, 2009). AHP method is arranged in several steps as follow:

1. Problem modeling by determining case goal, criteria and alternative.
2. Pairwise comparison by using a matrix to compare each node of the hierarchy.
3. Judgment Scales which can be assessed based on AHP Verbal Scale

Table 2.18 AHP Verbal Scale

Intensity of Importance	Definition
1	Equal importance
2	*
3	Moderate importance
4	*
5	Strong importance
6	*
7	Very strong importance
8	*
9	Extreme importance
*	(Intensity importance between previous and next scale)

(Source: Ishizaka and Labib, 2009)

4. Priorities derivation by using the comparison matrix with weighted criterion. The result of this step is weighted portion of each criterion.

2.6 Regression Analysis

Regression analysis is used to predict a contionous dependent variable from a number of independent variables (Abrams, 2007). Regression is widely used in statistical method to determine relationships between each variables. All included data in regression analysis must be in normal distribution condition and free of outliers. The basic formula of regression is mentioned in equation 2.5.

Regression type is basically divided into two, they are simple linear regression and standard multiple regression. These type of regression are used for same purpose, but in different condition of data.

2.6.1 Simple Linear Regression

Simple linear regression is used to predict values of one variable. The prediction is expressed by an equation of a line that fits through a cluster of points with a minimal amount deviations from the line. The deviation should be minimized because it can be considered as an error.

2.6.2 Standard Multiple Regression

Standard multiple regression has the same basic definition with simple linear regression, but it is added by several independent variables to predict the dependent variable. The value of prediction factors is denoted by R^2. Moreover, each factor can be determined as significant as long as it has equal or lower result than determined alpha (α) which commonly given as 0.05 or maximum 0.1.

2.7 Participatory Ergonomics

Participatory ergonomics is one of macro-ergonomics approach to maintain good relationship between technology-human and human-human which highly involved human interaction. Participatory mainly used bottom-up approach which means a decision making and the running of it are involving workers and front-liner supervisor participation start from problem identification until the creation of alternative solution. ‘A participative process to use the entire capacity of workers, designed to encourage employee commitment to organizational successes’ said Cotton (1993) in Industrial Management & Data Systems (2004).

2.8 Previous Researches

Since ATC workload is important to ensure the air traffic management and safety which commonly also becomes the air traffic capacity at once, many ATC workload measurements researches have been conducted from several years ago. The list and comparison between workload measurement approaches is given in the table 2.19.

Table 2.19 Comparison of Previous Researches

	Previous Research					
Year	1998	2003	2009	2013	2013	2015
Type	International Journal	International Journal	International Journal	Undergraduate Research	Undergraduate Research	International Journal
Author	I. V. Laudeman, S. G. Shelden, R. Branstrom and C. L. Brasil	Parimal Kopardekar and Sherri Magyarits	Parimal Kopardekar, Albert Scwartz and Sherri Magyarits	Jerry Budiman	Urwatuz Zahara	Amina Dervic and Alexander Rank

Table 2.19 Comparison of Previous Researches (Cont'd)

	Previous Research					
Title	Dynamic Density: An Air Traffic Management Metric	Measurement and Prediction of Dynamic Density	Airspace Complexity Measurement: an Air Traffic Control Simulation Analysis	Analisis Beban Kerja Operator Air Traffic Control Bandara XYZ dengan Metode NASA-TLX	Analisis Beban Kerja pada Operator *Air Traffic Control* untuk Mengurangi *Stress* Kerja (Studi Kasus: Bandar Udara Ahmad Yani Semarang)	ATC Complexity Measures: Formulas Measuring Workload and Complexity at Stockholm TMA
Object	ATC of Oakland Air Route Tracffic Control Center (ARTCC) and Ames Research Cnter	ATC of 4 ARTCC located at Atlanta, Cleveland, Denver and Fort Worth	Cleveland ARTCC	ATC of XYZ International Airport in Indonesia	ATC of Ahmad Yani International Airport, Semarang, Indonesia	APP Controller of ATCC Arlanda International Airport, Stockholm, Sweden
Method(s)	Dynamic Density (DD)	Developed DD with 4 complexity factors sets	Developed DD with 5 complexity factors sets	NASA-TLX	NASA-TLX, HEART and Risk Analysis	Developed DD with BEST RADAR Simulation Software
Output	Basic formula of DD	Developed DD with R^2 0.32 for the research workload measurement result	Developed DD with R^2 0.69 for the research workload measurement result	ATC workload measurement	ATC workload measurement, human reliability measurement and improvement in high risk categorized sectors	Developed DD with R^2 0.58 for the research workload measurement result

‘Analisis Beban Kerja Operator *Air Traffic Control* Bandara XYZ dengan Metode NASA-TLX’ or ‘Workload Analysis of Air Traffic Controller at XYZ Airport by Using NASA-TLX Method’ is a research conducted by Jerry Budiman in 2013 for his undergraduate research. The study case of this research is an XYZ International Airport in Indonesia which provides flight for domestic and international flight. Complexity of this airport is relatively high and correspondingly triggers the ATC workload. This research subjective workload measurement by using NASA-TLX is focused on APP Controller. This method uses 6-dimensional assessment consists of mental demand, physical demand, temporal demand, performance, effort, and frustration level. The result of NASA-TLX shows that mental demand such as thinking, decision making, calculating, remembering and seeing has high portion in ATC workload. Solutions to minimize the workload offered by the researcher are upgrade ATC surveillance system, better shifting management and fix the worker individual habits during work.

‘Analisis Beban Kerja pada *Operator Air Traffic Control* untuk Mengurangi *Stress* Kerja (Studi Kasus: Bandar Udara Ahmad Yani Semarang)’ or ‘Air Traffic Controller Workload Analysis to Diminish Work Stress (Study Case: Ahmad Yani Airport in Semarang)’ is a research conducted by Urwatuz Zahara for her undergraduate research. This research object has lack of facilities which trigger greater ATC workload, lower reliability and higher risk. The ATC workload, human reliability measurement, and risk mapping are measured by NASA-TLX, HEART, and Risk Analysis respectively. The results of these methods are related and integrated between one and another. Assessment by using NASA-TLX shows that 96% of ATC mental workload is triggered by cognitive demands, while the rest 4% is a portion of physical demand. Based on HEART method, the reliability of ATC is 0.89. Furthermore, the error level and potential of error which considered as risk are triggered by APP working location which near to crowded environment and the high level of workload is due to excessive working hour.

‘ATC Complexity Measures: Formulas Measuring Workload and Complexity at Stockholm TMA’ is an international journal and publication written by Amina Dervic and Alexander Rank. Study case in this research is Arlanda International Airport Stockholm airspace. FIR of Arlanda Airport ATC is divided into three, which are Control Zone (CTR), Terminal Maneuvering Area (TMA) and Control Area (CTA). TMA has the greatest complexity since this area not only covers flight directing and leaving the airport, but also passing through flight; therefore this research focuses on discussing about this area controlling complexity. This research discusses about workload measurement approached by considering complexity in the operator task load by using Dynamic Density (DD). This research states that actually there is still no objective method to measure the ATC workload accurately, it is because the ATC workload is very dynamic and perceived differently by each person time by time, but DD model is able to reflect most of the task load complexity which considered as ATC workload compared to Aircraft Count approach which commonly used by aviation federation in most countries.

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CHAPTER III
RESEARCH METHODOLOGY

Research methodology is structured and briefly explained in this chapter. This methodology is purposed to guide the research systematically by generated in a flowchart and explained narratively.

3.1 Research Flowchart

This research is conducted under structural procedure to make it well constructed and reliable. The flowchart is given as Figure 3.1.

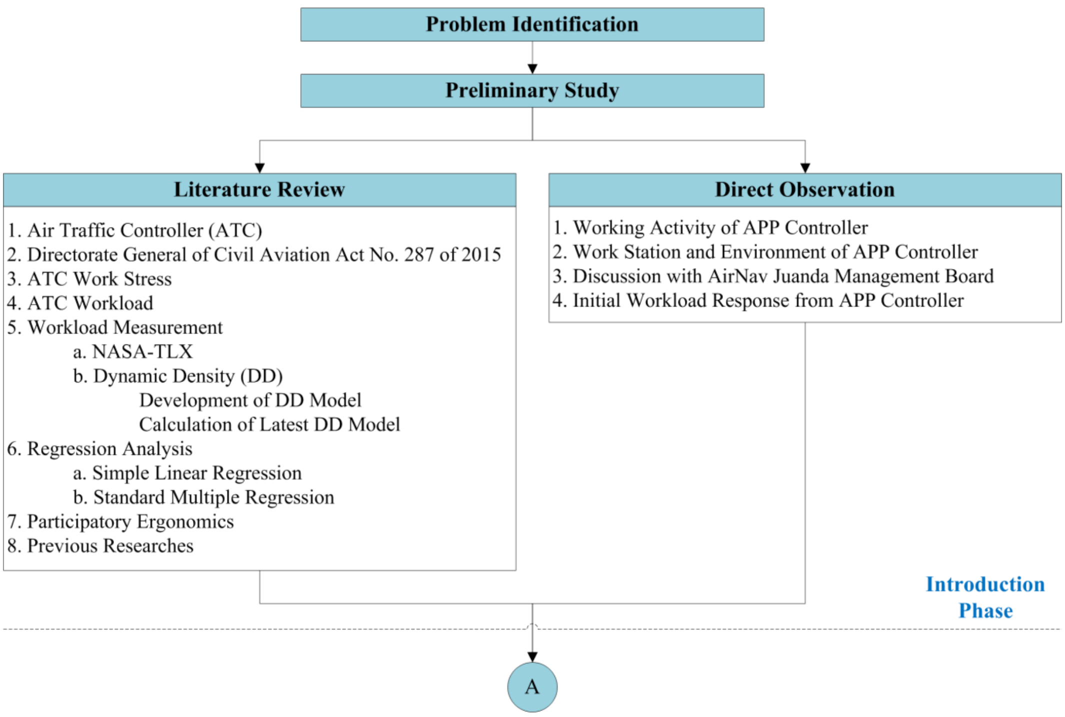

Figure 3.1 Research Flowchart

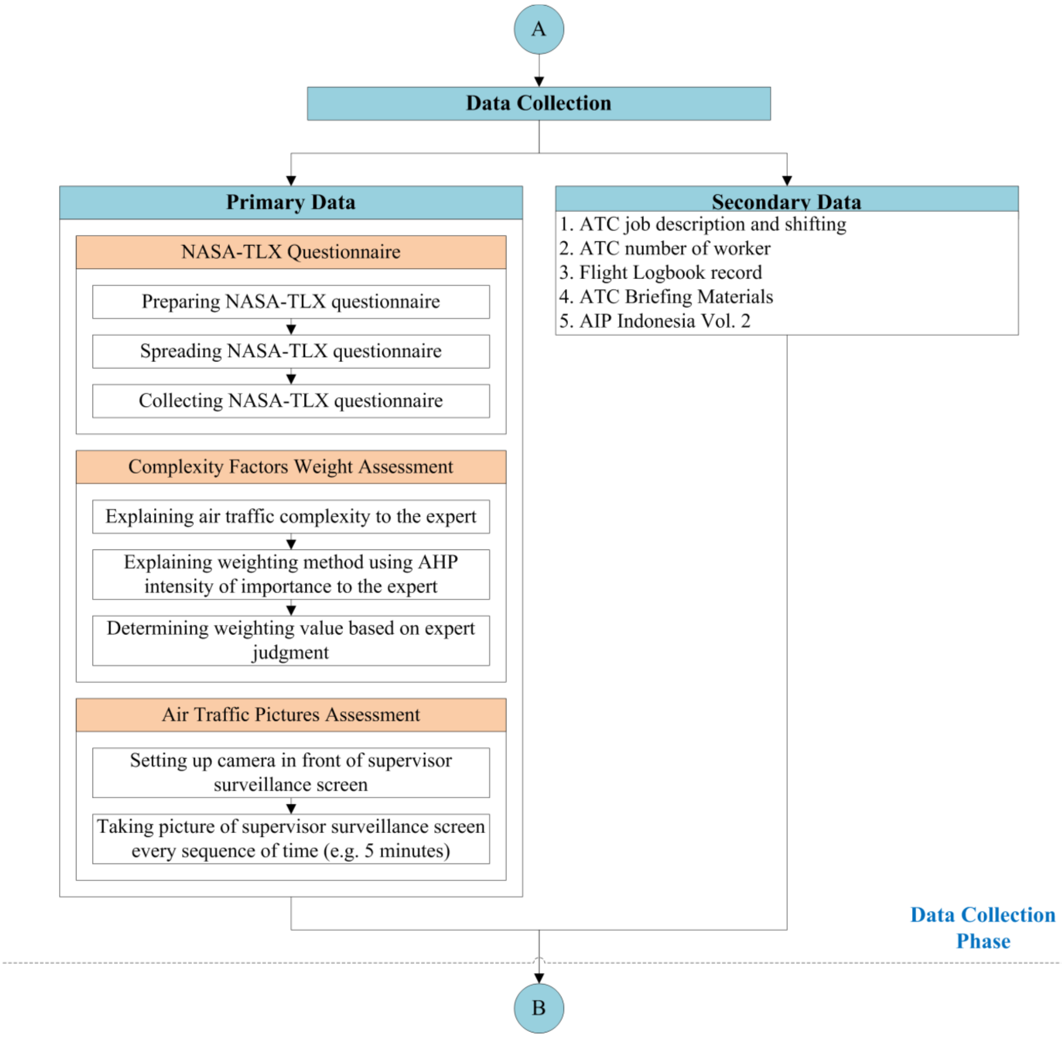

Figure 3.1 Research Flowchart (Cont'd)

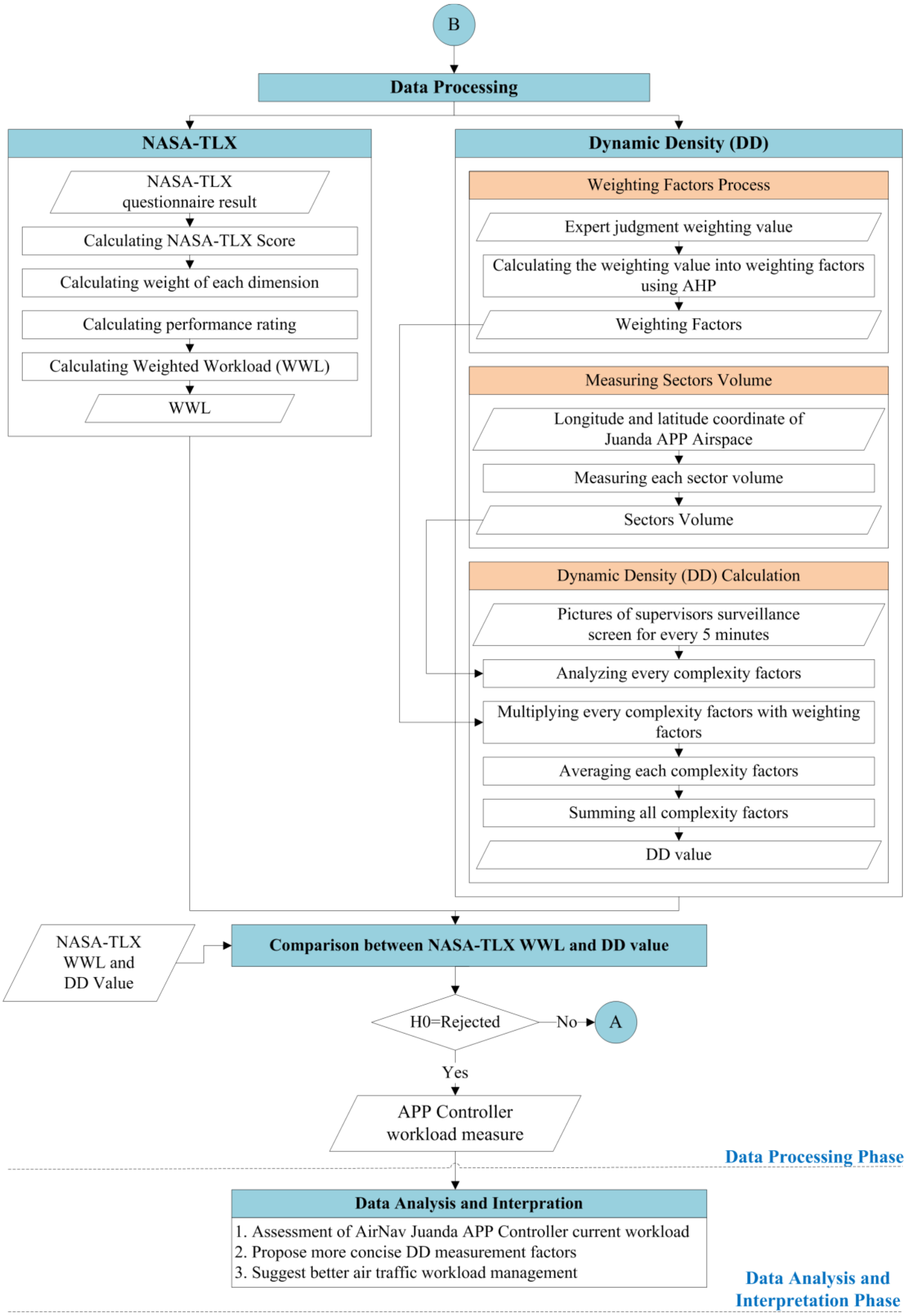

Figure 3.1 Research Flowchart (Cont'd)

3.2 Explanation of Research Flowchart

This subchapter is purposed to explain the flowchart which consists of several phases during research. The phases are Introduction Phase, Data Collection Phase, Data Processing Phase, Data Analysis and Interpretation Phase and Conclusion and Suggestion Phase.

3.2.1 Introduction Phase

Introduction phase mainly consists of background explanation, problem identification, objective determination and literature study and direct observation. Problem background is explained in advance to identify the basic problem and objective needed from study case, AirNav Juanda. After main problem has been well identified and the objective has been clearly defined, next the appropriate literature review and data observation used in this research are listed as follow:

- Literature Review

  This is a learning step of several related scientific studies and journals as ~~the~~ basic knowledge during working on research. Some topics discussed in Literature Review are ATC, Directorate General of Aviation Act No.287 of 2015, ATC work stress, ATC workload and its measurement which consists of NASA-TLX and DD, Analysis of Variance (ANOVA) and also previous researches.

- Direct Observation

  This step is purposed to make the depiction of the object, AirNav Juanda, defined clearly. It must be obtained to ensure the problem solving methods are chosen appropriately and able to be applied with the observation data. The data that directly observed from the object are working activity, work station and environment and initial workload response of APP Controller which strengthen by discussion with AirNav Juanda Management Board.

3.2.2 Data Collection Phase

This phase is ordered to collect data to be processed in problem solving methods. The collected data are divided into primary data and secondary data. The primary data is obtained by NASA-TLX questionnaire which started from questionnaire preparing, spreading and collecting. The secondary data consists of

ATC job description and shifting, number of worker, Flight Logbook record, ATC Briefing Materials and AIP Indonesia Vol.2 (2010).

3.2.3 Data Processing Phase

After the data collection is accomplished, data processing phase can be run. The process is divided into two which are:

- NASA-TLX

  Started from the result of NASA-TLX questionnaire is scored by using NASA-TLX scoring calculation, and ~~then~~ continued to weight of each dimension, next is calculating the performance rating and the last is obtaining WWL. Then result of WWL is used as the validation of DD and vice versa by comparing it with the DD value.

- DD

  DD calculation is divided into three main parts which are weighting factors process, measuring sectors volume and calculating Dynamic Density (DD. Below is the explanation of each step:

  1. Weighting factors process consists of calculating the weighted value which obtained from expert judgment using Analytical Hierarchy Process (AHP) into categorized weighting factors.
  2. Measuring sectors volume is a separated process since the exact volume APP airspace is not measured yet by AirNav Juanda. The result of this measurement becomes the input of DD complexity factors assessment.
  3. In calculating the APP Controller workload measure using DD, the first step is analyzing every complexity factors presented by pictures taken from supervisor surveillance screen. Since the pictures are taken every five minutes, the result of each factor should be averaged before being multiplied by each weighting factor. After that the multiplied factors and their weighting can be summed as a DD value of each APP Controller.

After NASA-TLX WWL and DD value of each observed APP Controller have been obtained, both values can be compared by conducting a simple linear regression. It is purposed to conduct a validation of DD as objective method by

NASA-TLX as subjective method which already had classified level of mental workload value.

3.2.4 Data Analysis and Interpretation Phase

After the comparison of NASA-TLX and DD has been done, the result can be comprehensively analyzed and interpreted. The analysis and interpretation consists of AirNav Juanda APP Controller current workload assessment, more concise DD measurement factors proposal and better air traffic workload management suggestion.

CHAPTER IV
DATA COLLECTION AND PROCESSING

This chapter is purposed to show some important data and the result of processing data. Furthermore, it consists of company profile of AirNav Indonesia, workload measurement using DD and NASA-TLX and result validation.

4.1 Company Profile of AirNav Indonesia

AirNav Indonesia is a company which has main responsibility to manage air traffic smoothness in an authorized area. Registered name of AirNav Indonesia is *Perusahaan Umum Lembaga Penyelenggara Navigasi Penerbangan* Indonesia (Perum LPPNPI). This company has several subsidiaries which are spread on almost all airports in Indonesia. Further explanation about this company is explained in the following subchapters.

4.1.1 Company Profile of AirNav Indonesia

AirNav Indonesia is a State Owned Enterprise with legal name as *Perusahaan Umum Lembaga Penyelenggara Pelayanan Navigasi* Indonesia (*Perum* LPPNI). Since all share of this company is owned by Ministry of State Owned Enterprise, AirNav Indonesia is not intended as a profit oriented enterprise, but to ensure the safety of air traffic in Indonesia. This company was established under Government Regulation (PP) No. 77 year 2012 in 16th January 2013 on 10 PM of Indonesia Western Standard Time (WIB) or 17th January 2013 on 12 AM of Indonesia Eastern Standard Time (WIT).

Figure 4.1 Logo of AirNav Indonesia
(Source: airnavindonesia.co.id, 2013)

Before Indonesia air traffic navigation lies on AirNav Indonesia management, the responsibility been authorized under PT Angkasa Pura I and II. But these companies have double duty to manage land sector, which is airport with all its derivative tasks, and navigation sector. In 2005 and 2007, International Civil Aviation Organization (ICAO) conducted Universal Safety Oversight Audit Program and Safety Performance) and result of the audits showed that Aviation in Indonesia did not fulfill minimum safety requirement of ICAO Safety International Standard yet. Hence ICAO recommended Indonesia to make a single establishment to manage navigation service for air traffic in Indonesia.

In September 2009, *Rancangan Peraturan Pemerintah* (RPP) was created as legal basis to make *Perum* LPPNPI. In 13th September 2012, President Susilo Bambang Yudhoyono inaugurated the RPP into *Peraturan Pemerintah* (PP) No. 7 year 2012. According to the regulation, all the navigation and technical service unit responsibility are transferred from PT Angkasa Pura I and II to *Perum* LPPNPI or widely known as AirNav Indonesia. Started from 16th January 2013, AirNav Indonesia handles the navigation service to manage air traffic in Indonesia based on rules and standard procedure that strictly regulated by Civil Aviation Safety Regulation (CASR).

As an independent organization with a corporate form, AirNav Indonesia has vision, mission and several values to make this company achieve better efficiency and effectiveness. Its vision is to become the best Air Navigation Service Provider (ANSP) in South East Asia. This vision is supported by a mission to provide air traffic service which prioritizes safety, convenient and environmentally friendly to fulfill customer satisfaction. To achieve the vision, this company set five values which abbreviated as I SAFE; the values are: 1) Integrity: upholding truth and ethics, 2) Solidity: prioritizing truth and ethics; 3) Accountability: brave, honest and responsible; 4) Focus and Safety: prioritizing safety; and 5) Excellent Service: always give the best service.

Since scope of AirNav Indonesia service is covering all FIR of Indonesia, this company divvies the duty to 8 branches and 19 districts. The branches and districts are listed on the Table 4.1,

Table 4.1 AirNav Indonesia Branches and Districts

No	Branch	District	No	District
1	JATSC Jakarta	Ambon	11	Manado
2	MATSC Makassar	Banda Aceh	12	Padang
3	Balikpapan	Bandung	13	Pangkal Pinang
4	Denpasar	Banjarmasin	14	Pekanbaru
5	Medan	Batam	15	Pontianak
6	Palembang	Biak	16	Semarang
7	Surabaya	Halim Jakarta	17	Solo
8	Sentani	Jambi	18	Tanjung Pinang
9		Kupang	19	Yogyakarta
10		Lombok		

(Source: airnavindonesi.co.id, 2013)

4.1.2 Company Profile of AirNav Juanda

AirNav Juanda is one of AirNav Indonesia branches which located in Juanda Airport at Jl. Ir. Haji Juanda, Sidoarjo, East Java. This branch was inaugurated on 26th January 2015 by Chief of Airport Authority Region III Surabaya.

Figure 4.2 Company Sign of AirNav Indonesia Surabaya Branch

(Source: airnavindonesia.co.id, 2013)

Based on PER005/LPPNPI/X/2013, branch office is ordered to provide air traffic service which consists of air traffic operations, operation and flight navigation facilities repair as well as activities management and control, finance and administration accordance to policies outlined by directors to support the operational and development of branch office.

AirNav Juanda is supported by its employees in structured job division. The organizational structure and functional is given in the following page as figure 4.3.

Refer to the figure 4.3, Air Traffic Service Junior Manager manage the ATC as his subordinates. But in daily operational, the ATC is under supervisor and responsibility of ATS Operation Coordinator.

Based on their working area, ATC Juanda is classified into two units which are Juanda Tower Unit (TWR) and Juanda Approach Unit (APP). TWR is separated into 2 sectors, which are Juanda Ground Sector and Juanda Tower Sector, with one supervisor to control all TWR Sectors at once in one cycle. Number of ATC at TWR is 25 personnel with 9 supervisors. While, APP is divided into 3 sectors, which are Sub-Director Sector (Director), TMA West (TMAW) and TMA East (TMAE), with one supervisor for Director and one more supervisor for TMAW and TMAW. Even sometime TMA West and TMA EAST are handled by one operator and also sometime the supervisor assigned for these sectors is only one since the number of ATC in AirNav Juanda is shorthanded. Number of ATC at APP is 32 personnel with 16 supervisors.

APP Controller tasks are much more complicated than TWR Controller tasks because APP requires skill of traffic controlling using surveillance device. The area and altitude of APP make this unit has to sequence and manage the aircrafts which depart either direct to Juanda Airport. While the TWR only continue the clearance from APP which means the route and sequence of those aircrafts are under the APP decision.

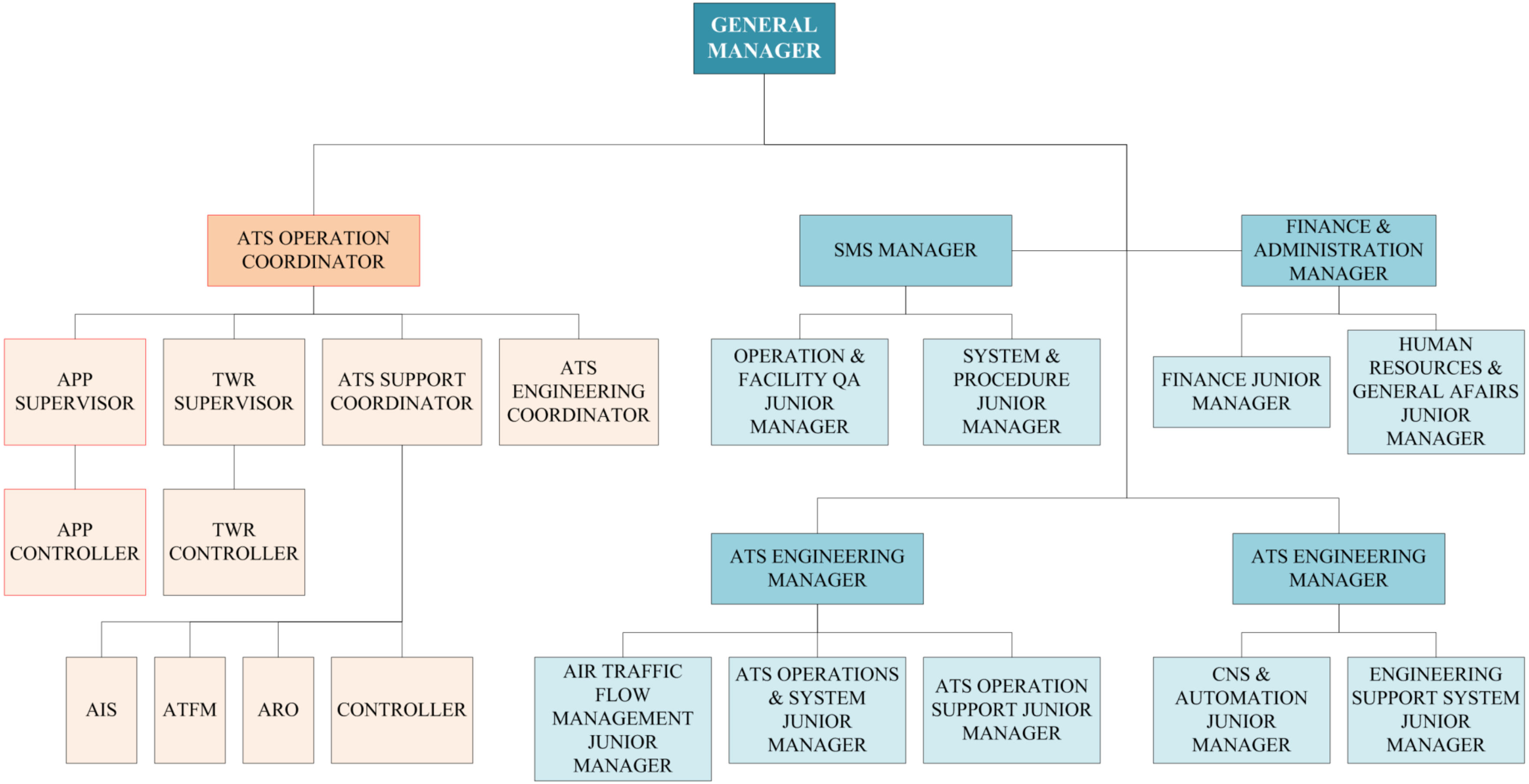

Figure 4.3 AirNav Juanda Organizational Structure

(Source: AirNav Indonesia, 2013)

4.1.3 APP Controller Tasks during Providing Air Traffic Service

Based on AirNav Juanda SOP Manual Book about APP Controller (2015), the tasks during controlling are listed below:

1. Always relying on air traffic procedure and shall always prioritizing safety first.
2. Coordinating with internal ATC under AirNav Juanda and external ATC as good as possible.
3. Coordinating with internal and external units in accordance to Letters of Authorization (LOA).
4. Record all important matters regarding air traffic service and supporting facilities condition.
5. In case facing problem that cannot be solved solely, report the matters to supervisor or chief.

4.2 Workload Measurement Using DD

DD is the objective method to measure APP Controller mental workload. Moreover, there are several raw materials data that must be fulfilled and processed in order to know the DD value of each respondent, who is AirNav Juanda APP Controller. The steps are determining weighting factors, measuring each sector volume and calculating the DD of each respondent.

4.2.1 Weighting Factors

DD consists of several complexity factors which have different portion in affecting ATC mental workload. In purpose determine the weight of each factor, AHP as prioritization based on expert judgment can be used to convert the subjective expression into numerical value of weight.

4.2.1.1 Weighting Factors Assessment

In order to get the weighting of each factor, an interview is conducted to obtain expert judgment from AirNav Juanda Air Traffic Service Junior Manager, Aji Kuspitono. Based on his 11 year experience on APP surveillance controlling, completed with 4 year experience to manage quality of AirNav Juanda Air Traffic Service, including monthly schedule plotting of ATC assignment by considering approximation of workload allocation and the involved ATC experience, the interview was well conducted and can be stated as reliable to presents the real portion of each DD factors in APP Juanda airspace. The result of expert judgment based on the interview is attached in appendix 2.

Since it is a subjective expert judgment, the weighting is determined using Analytical Hierarchy Process (AHP). The interview to obtain the expert's response was conducted with triggering questions of each complexity factor significant level. Therefore the result of this AHP can be used as weighting of DD complexity factors. Furthermore, the detailed AHP processing results are given in appendix 2 and the summaries are listed on the tables 4.2 until 4.4.

Table 4.2 Result of DD 17 Complexity Factors AHP

AHP of 17 Complexity Factors	Average (Weight)	Rank
S5	0.1913	**1**
NUMHORIZ	0.1055	**2**
C15	0.0786	**3**
SCI	0.0765	**4**
SV	0.0643	**5**
C9	0.0639	**6**
AC	0.0637	**7**
AD1	0.0622	**8**
WB PROX	0.0596	**9**
S10	0.0577	**10**
C11	0.0444	**11**
HDG VARI	0.0354	**12**
WASP	0.0232	**13&14**
AXIS HDG	0.0232	
C16	0.0191	**15**
WCONVANG	0.0165	**16**
C2	0.0149	**17**
Total	1.0000	

In purpose to efficient the processing time of DD analysis, the result of AHP also can be used to prioritize assessed complexity factors. This research sequence the factors assessment into two types of based on number of factors assessed. The first one is DD assessment with considering highest 5 significant factors (DD_5), the next assessment is considering highest 10 significant factors (DD_{10}). Since AHP is a pair comparison factors based on expert judgment, each set of assessment factors must be re-analyzed using AHP as presented on tables below,

Table 4.3 AHP of DD 5 Complexity Factors

AHP of 5 Complexity Factors	Average (Weight)	Rank
S5	0.5643	**1**
NUMHORIZ	0.2083	**2**
SCI	0.1187	**3**
SV	0.0622	**4**
C15	0.0465	**5**
Total	1.0000	

Table 4.4 AHP of DD 10 Complexity Factors

AHP of 10 Complexity Factors	Average (Weight)	Rank
S5	0.3107	**1**
NUMHORIZ	0.1408	**2**
SCI	0.0910	**3**
SV	0.0847	**4**
C15	0.0728	**5**
AC	0.0670	**6**
WB PROX	0.0662	**7**
C9	0.0632	**8**
AD1	0.0598	**9**
S10	0.0439	**10**
Total	1.0000	

4.2.2 Sectors Volume Measurement

According to data from AirNav Juanda SOP (2015) and AIP Vol. 2 (2016), the volume of each APP Juanda sector can be measured. Visualization figures of APP Juanda airspace are given in the appendix 3. The result of each sector volume is listed in the table 4.5,

Table 4.5 Sector Volume Measurement Result

Sector	Area (m^2)	Height (m)	Volume (m^3)	Volume (NM^3)
TMAW	68,105,971,536.80	4419.60	301,001,151,804,041.00	47385.47
TMAE	47,985,041,507.90	4419.60	212,074,689,448,315.00	33386.12
Director	5,924,419,190.60	3042.00	18,022,083,177,805.20	2837.15
Airspace Volume			531,097,924,430,161.00	83608.74

4.2.3 Ten DD Complexity Factors Calculation

In the process of obtaining data to measure the value of DD, there are 11 rounds of 70-minutes of controlling collected. Every controlling round consists of 3 sectors except at night there are only 2 sectors (director and TMAW). The data is presented in pictures of APP Controller supervisor surveillance screen for every 5 minutes of interval time. The representatives of these pictures can be seen on the appendix 4. From the collected pictures, detailed complexity factors assessment can be well conducted. The calculations or assessments of these complexity factors are generated on appendix 5 and the explanations or detailed process are listed below:

- Calculation of S5

  Thorough assessment is conducted to every single pictures collected to determine number of aircraft with separation between 0-5 NMs (excluding violations). There are some aircrafts captured with separation lower than 5 NMs, but they can be considered as legal (not a violation) because these aircrafts using self-visual separation maintaining under military training purpose. The cases were captured in morning shift of 4th and 5th May 2017.

- Calculation of NUMHORIZ

  NUMHORIZ is a similar factor toward S5, it is also about aircraft separation, but focused on below 8 NMs. This is an efficient aircraft separation, but requires intense controller attention to ensure the safety of the aircrafts. Thorough assessment found that 8 NMs separation is a common thing hence it almost included in every round of traffic-controlling.

- Calculation of SCI

  In order to calculate SCI, each aircraft horizontal separation divided by lateral minima (SIH) and vertical separation divided by vertical minima (SIV) must be thoroughly paired-measured in advance. After that, the SCI can be calculated as well. Below is example of director sector at 15.30 UTC +7 of 2nd May 2017 SCI calculation (table 4.6 until 4.10).

Table 4.6 Real Horizontal Separation of Each Paired Aircrafts (in NM)

Director (NM)	GIA 7308	LNI 604	L567	GIA 670	BTK 7515
GIA 7308	0	0	0	0	0
LNI 604	16.8	0	0	0	0
L567	28	28	0	0	0
GIA 670	16.8	16	20	0	0
BTK 7515	42.4	49.6	52	33.6	0

Table 4.7 SIH of Each Paired Aircrafts

Director (NM)	GIA 7308	LNI 604	L567	GIA 670	BTK 7515
GIA 7308	0				
LNI 604	3.36	0			
L567	5.6	5.6	0		
GIA 670	3.36	3.2	4	0	
BTK 7515	8.48	9.92	10.4	6.72	0

(Note: SIH $\leq$ 4; red colored value is SIH that $\geq$ than 4)

Table 4.8 Real Vertical Separation of Each Paired Aircrafts (in 100ft)

Director (100ft)	GIA 7308	LNI 604	L567	GIA 670	BTK 7515
GIA 7308	0				
LNI 604	86	0			
L567	13	13	0		
GIA 670	73	6	113	0	
BTK 7515	114	25	1	78	0

Table 4.9 SIV of Each Paired Aircrafts

Director (100ft)	GIA 7308	LNI 604	L567	GIA 670	BTK 7515
GIA 7308	0				
LNI 604	8.6	0			
L567	1.3	1.3	0		
GIA 670	7.3	0.6	11.3	0	
BTK 7515	11.4	2.5	0.1	7.8	0

(Note: SIH ≤ 4; SIV ≤ 2; blue colored value is SIV that ≥ than 2)

Table 4.10 SI of Each Paired Aircrafts

Director	GIA 7308	LNI 604	L567	GIA 670	BTK 7515
GIA 7308	0	0	0	0	0
LNI 604	5.98	0	0	0	0
L567	3.45	3.45	0	0	0
GIA 670	5.33	1.9	7.65	0	0
BTK 7515	9.94	6.21	5.25	7.26	0

(Note: SIH ≤ 4; SIV ≤ 2; SI ≤ 3; yellow shaded value is SI that fulfill the determined conditions)

$$SCI = (3 - 1.9)^2 = 1.21$$

From the calculation above, the SCI of director sector at 15.30 UTC +7 of 2nd May 2017 is 1.21. Then the same procedure is applied to all the following traffic assessment.

- Calculation of SV (Can be seen in sub chapter 4.2.2)
- Calculation of C15

Below is the example of C15 calculation process of director sector at 15.30 UTC +7 of 2nd May 2017 (table 4.11).

Table 4.11 Speed Variation of Aircrafts

GIA 7308	LNI 604	L567	GIA 670	BTK 7515
212	168	105	204	300

$$\bar{V} = \frac{212 + 168 + 105 + 204 + 300}{5} = 197.8$$

$$\sigma_{vg}{}^{2} = \frac{(212 - 197.8)^2 + (168 - 197.8)^2 + (105 - 197.8)^2 + (204 - 197.8)^2 + (300 - 197.8)^2}{(5 - 1)}$$

$$= 5046.2$$

$$C15 = \frac{\sqrt{5046.2}}{197.8} = 0.0795$$

- Calculation of AC

  This factor presents the number of aircraft in a sector authorized by an APP Controller. This is the basic concept of conventional objective ATC workload measurement method.

- Calculation of WB PROX

  WB PROX presents the number of aircraft within a threshold distance towards a sector boundary. It affects the APP Controller workload because the aircraft need to be transferred or accepted between two or more controllers in different authorized sector. In Juanda air traffic, the threshold is determined as 20 NMs. So, WB PROX is used to presents the number of aircraft within 20 NMs from the sector boundary. Moreover, the WB PROX assessment method is same with AC.

- Calculation of C9

  Below is the example of C9 calculation process of director sector at 15.30 UTC +7 of 2nd May 2017.

  Retrieve to table 4.6 and select the minimum separation in the assessed sector (table 4.12).

Table 4.12 Minimum Separation of Each Paired Aircrafts

Director (NM)	GIA 7308	LNI 604	L567	GIA 670	BTK 7515
GIA 7308	0	0	0	0	0
LNI 604	16.8	0	0	0	0

Table 4.12 Minimum Separation of Each Paired Aircrafts (Cont'd)

Director (NM)	GIA 7308	LNI 604	L567	GIA 670	BTK 7515
L567	28	28	0	0	0
GIA 670	16.8	16	20	0	0
BTK 7515	42.4	49.6	52	33.6	0

$$C9 = \frac{1}{16} = 0.0625$$

- Calculation of AD1

  Method to calculate AD1 is same with AC, but then the result is divided by airspace volume. As AC, AD1 is also the basic concept of conventional objective ATC workload measurement method.

- Calculation of S10

  Method to calculate S10 is same with S5, but the considered factor is aircrafts separation which is between 5-10 NMs. Actually this separation is efficient, but demands attention from the APP Controller to ensure the traffic safety and smoothness.

4.2.4 DD Value Calculation

Based on the data obtained from weighting and complexity factors assessment, the DD value of two determined set of factors (5 and 10 consideration factors) can be calculated. Below is an example of DD_5 and DD_{10} of 1^{st} APP Controller calculation

$$DD_5 = S5(0.564) + NUMHORIZ(0.208) + SCI(0.119) + SV(0.062) + C15(0.0466)$$

$$DD_5 = 0(0.564) + 0.8(0.208) + 0.488(0.119) + 2837.148(0.062) + 0.25(0.0466) = 176.579$$

$$DD_{10} = S5(0.3107) + NUMHORIZ(0.1408) + SCI(0.0910) + SV(0.0847) + C15(0.0728) + AC(0.0670) + WBPROX(0.0662) + C9(0.0632) + AD1(0.0598) + S10(0.0439)$$

$$DD_{10} = 0(0.3107) + 0.8(0.1408) + 0.488(0.0910) + 2837.148(0.0847) + 0.25(0.0728) + 2.8(0.0670) + 1.7(0.0662) + 0.07(0.0632) + 0.000035(0.0598) + 0.8(0.0439) = 240.698$$

Then, this procedure applied to measure the following APP Controllers DD value.

4.3 Workload Measurement Using NASA-TLX

NASA-TLX is one of most well-known subjective mental workload measurement methods. This method is widely used because covers 6 dimensions of mental workload indicator.

4.3.1 NASA-TLX Assessment Result

NASA-TLX questionnaires (appendix 6) were given to the APP Controller once they had finished one round of controlling (70 minutes of controlling). Every one round of controlling, mostly divided into three sectors, and only two sectors after 7 PM, are run by a main controller on each sector. The detailed result of questionnaire spread to AirNav Juanda APP Controller is attached on appendix 7 and the summary is given in table 4.13.

Table 4.13 NASA-TLX Assessment Result

APP Controller	Experience		Sector	WWL	Classification
	APP Rating (Years)	Controlling for AirNav Juanda (Years)			
1	15	16	Director	60	High
2	9	5	TMAW	66.667	High
3	17	12	TMAE	66.667	High
4	13	18	TMAW	74	High
5	4	9	Director	62.133	High
6	14	14	TMAW	82	Very High

Table 4.13 NASA-TLX Assessment Result (Cont'd)

APP Controller	Experience		Sector	WWL	Classification
	APP Rating (Years)	Controlling for AirNav Juanda (Years)			
7	3	4	TMAE	64	High
8	15	15	Director	63.333	High
9	12	12	Director	62	High
10	14	4	TMAW	78	High
11	18	6	TMAE	65.333	High
12	30	30	Director	58	High
13	4	7	Director	62.667	High
14	3	3	TMAW	68	High
15	3	3	TMAE	67.333	High
16	4	18	Director	60.333	High
17	16	16	TMAW&E	86	Very High
18	20	38	Director	63.333	High
19	16	16	TMAW	70.333	High
20	4	11	TMAE	55	High
21	3	17	Director	45.333	Medium-High
22	13	16	Director	49.667	Medium-High

4.3.2 NASA-TLX Data Adequacy Test

To ensure NASA-TLX questionnaire confidence level, standard deviation and adequacy, a data adequacy test must be done. Furthermore, the result of the test is given in calculation below which supported by data in table 4.14,

$$N' = \left(\frac{\frac{1.645}{0.05}\sqrt{22(94842.772 - (1430.133)^2}}{1430.133} \right)^2$$

$$N' = \left(\frac{32.897\sqrt{2085641.013 - 2045281.351}}{1430.133} \right)^2$$

$$N' = \left(\frac{32.897\sqrt{41259.662}}{1430.133} \right)^2$$

$$N' = \left(\frac{32.897(203.125)}{1430.133}\right)^2$$

$$N' = \left(\frac{6682.209}{1430.133}\right)^2 = (4.672)^2 = 21.832 \approx 22$$

Table 4.14 Total of X_i and X_i^2 for NASA-TLX Data Adequacy Test

No	WWL Variance (X_i)	X_i^2	No	WWL Variance (X_i)	X_i^2
1	60	3600	12	58	3364
2	66.667	4444.444	13	62.667	3927.111
3	66.667	4444.444	14	68	4624
4	74	5476	15	67.333	4533.778
5	62.133	3860.551	16	60.333	3640.111
6	82	6724	17	86	7396
7	64	4096	18	63.333	4011.111
8	63.333	4011.111	19	70.333	4946.778
9	62	3844	20	55	3025
10	78	6084	21	45.333	2055.111
11	65.333	4268.444	22	49.667	2466.778
Total				**1430.133**	**94842.773**

From the table above, with 95% of confidence level and 5% of standard deviation threshold, it can be defined that the amount of data or questionnaire needed is 22 data. Since the obtained data is 22 questionnaires, so the NASA-TLX amount of data is confirmed as adequate.

4.4 Regression of DD and NASA-TLX

In purpose to draw the APP Controller workload pattern of DD and NASA-TLX, a simple linear regression is used to generate. It is because both of them are used to measure same object with same purposed output, which is workload level illustration. Therefore DD and NASA-TLX result can drawn and the significant level can be measured by using regression. The result of DD and NASA-TLX regression with 95% of confidence level is given in the table 4.15 and 4.16.

Table 4.15 H0 Assessment of DD Regression

	DD_5		DD_{10}	
	Intercept	**X Variable 1**	**Intercept**	**X Variable 1**
Coefficients	56.99387648	0.005090983	56.99273354	0.003737735
Standard Error	1.944123075	0.000919882	1.944232999	0.000675348
t Stat	29.3159817	5.534383769	29.31373635	5.534535297
P-value	6.58929E-18	2.03837E-05	6.59918E-18	2.03768E-05
Lower 95%	52.93850681	0.003172141	52.93713457	0.002328984
Upper 95%	61.04924616	0.007009824	61.04833251	0.005146485

Where:

(H0 Accepted)= No relationship between NASA-TLX WWL and DD Value

(H0 Rejected) = Relationship between NASA-TLX WWWL and DD Value exists

Since the result of DD_5 and DD_{10} are out of lower and upper 95% value, their H0 are rejected. Which means DD_5 and DD_{10} value have relationship with NASA-TLX WWL.

Table 4.16 Regression of DD Value toward NASA-TLX WWL

Regression Statistics	DD_5	DD_{10}
R Square	0.60497263	0.60498572
Adjusted R Square	0.58522127	0.585235006
Standard Error	6.0862542	6.086153393
Observations	22	22

The result of DD_5 R^2 is 0.60497263, while DD10 is 0.64998572. Different between DD_5 and DD_{10} R_2 value is about 0.00001309.

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5. CHAPTER 5
DATA ANALYSIS AND INTERPRETATION

This chapter discusses about workload experienced by the APP Controller based on objective and subjective approach; based on these approach, several improvement regarding significant factors to minimize APP Controller workload can be determined. The objective approach is Dynamic Density (DD) and the subjective one is NASA-TLX.

5.1 APP Controller Weighting Complexity Factors

Since all airspace has different condition that cause different controller common natural response, a specified weighting complexity factors need to be done in particular. By interviewing the expert of APP Controller in order to formulate expert judgment for weighting factors, the qualitative response can be generated into quantitative value. Then by using AHP, the quantitative data converted into weighting factors among the specified set (17, 5 and 10 factors).

From the AHP result of proposed complexity factors by Kopardekar, the top 5 and 10 factors can be determined and assessed as well. It is purposed to be used in the following process to finally show the regression different range between DD_5 and DD_{10} result. If the regression result of DD_{10} is much better than DD_5, so the highest 10 factors should be considered, it even better if all the 17 factors can be included. In the other hand, if the regression result of DD_{10} is much lower than DD_5, it means that these 5 highest weighted factors have been able to represent AirNav Juanda APP Controller workload. Since different between DD_5 and DD_{10} R^2 value is about 0.00001309, which is relatively small, then DD_5 already represents most of the complexity factors which determine the AirNav Juanda APP Controller workload.

5.2 APP Controller Workload Measurement

In order to measure APP Controller workload, there are two methods used in this research. The methods are DD as objective approach and NASA-TLX as subjective one. Since these methods have same main purpose, the results should tend to be directly proportional because the observational objects and conduction time are same. The importance of these methods used is because they have complementary advantages and disadvantages. The DD strengths are its ability to structured presenting the APP mental workload and mapping each complexity factor significant level, so workload management can be better conducted and measurable. Meanwhile, the main weakness of DD is no workload level classification of DD value range. Therefore the second method used as complementary and comparison is NASA-TLX which has the workload level classification. The comparison is purposed to measure DD relevancy level towards individual subjective workload response of observed APP Controllers.

5.2.1 APP Controller Workload Measurement using DD

The AirNav Juanda APP Controller workload measurement using DD is conducted under two approaches. The first is DD_5, while the second one is DD_{10}. Every complexity factors that consisted in each picture obtained from APP Controller supervisor screen is measured. After that, every factor value obtained is averaged based on the operator. The result can be seen on appendix 5.

The result of DD_5 calculation compared to DD_{10} shows a directly proportional graph as figure 5.1. Consistently, APP Controllers DD value which described by DD_5 are also presented as high by DD_{10}, and vice versa. This consistency is rationally happened because DD is an objective method. It means, DD objectively represents a nature of workloads generated by tasks and events complexity in the work itself. It also presents that DD_5 already sufficient to represents most of the APP Controller workload triggering factors.

From the result of DD_5 values presented in appendix 5 for the highest, average and lowest are 5020.396, 1573.799 and 176.3376 respectively. The highest value of DD_5 comes from APP Controller number 17 with WWL category as ‘very high’. For the average value, the closest DD value is owned by APP Controller number 20 with WWL category as ‘high’. While the lowest value is owned by APP Controller number 21 with WWL category as ‘medium high’. Which mean, the extreme and general result of DD able to represent pattern of workload experienced APP Controller with relatively same category with NASA-TLX as subjective method.

Furthermore, from the result presented in appendix 6, the portion of SV in total of DD_5 value is the highest (with about 99%). And then followed by NUMHORIZ (0.047%), SCI (0.021%), S5 (0.006%) and C15 (0.003%). Which means the workload experienced by APP Controller is mostly determined by the area covered under his/her authority, because every enlargement of area covers more traffic condition and requires higher attention. This factor is followed by separation issues that should be managed by APP Controller start from horizontal separation, separation criticality index and number of aircraft with distance for 0-5 NM excluding violation. And then the last is speed variation between each aircraft in a sector authorized by an APP Controller.

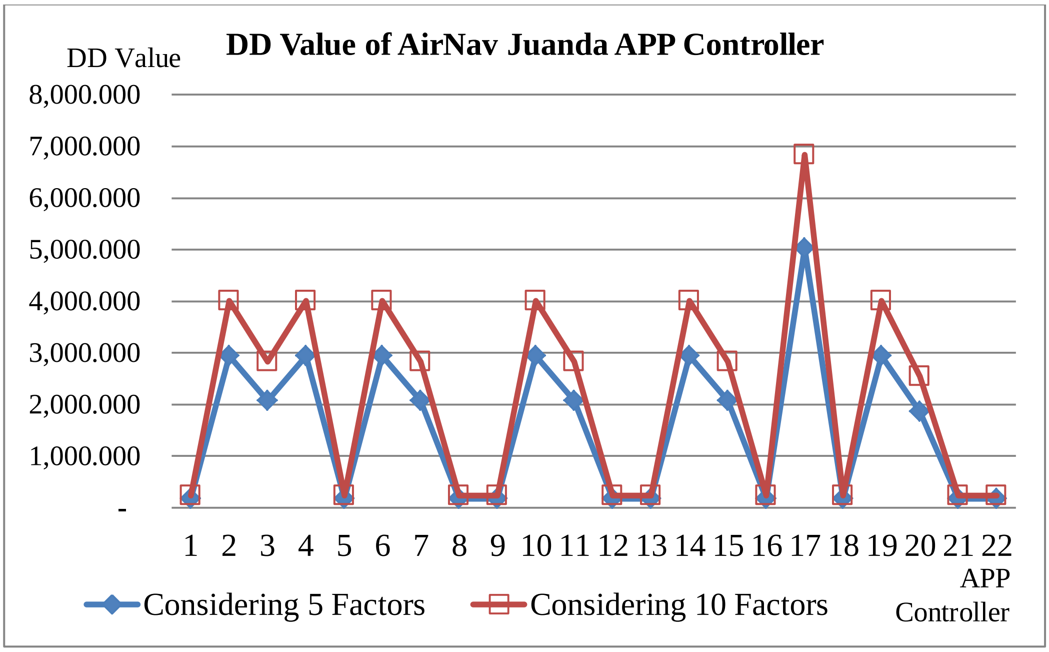

Figure 5.1 DD Value of AirNav Juanda APP Controller

5.2.2 APP Controller Workload Measurement using NASA-TLX

NASA-TLX is a subjective workload measurement method which widely used. It is because work-dimension measurement covered by NASA-TLX is the most comprehensive compared to other subjective methods. The workload burdened to the APP Controller is 9.1%, 81.8% and 9.1% ‘very high’, ‘high’ and ‘medium high’ high respectively.

Considering the questionnaire result that spread to the 22 observed APP Controllers just after they finished controlling, the workload individual responses regarding their last traffic controlled are obtained. These traffics are traffics that observed by DD too. Furthermore, these responses converted into countable NASA-TLX indicators which can be assessed into WWL of every observed APP Controller. Moreover, figure 5.2 presents the result of APP Controller workload measurement using NASA-TLX.

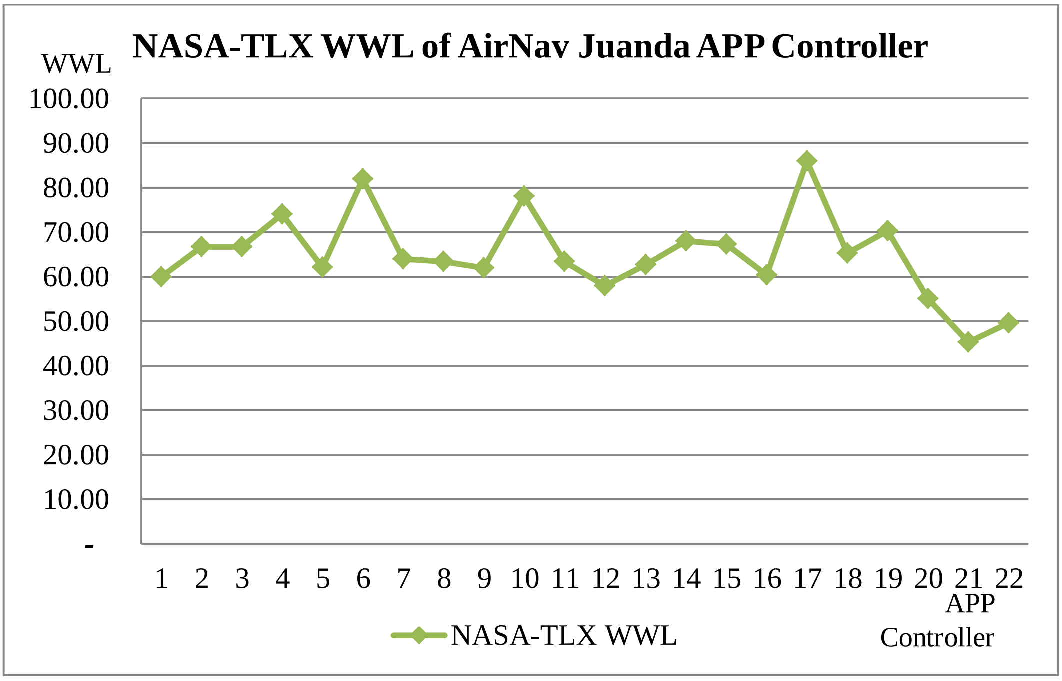

Figure 5.2 NASA-TLX WWL of AirNav Juanda APP Controller

5.2.3 *Linear Regression of DD Value and NASA-TLX WWL*

The result of linear regression shows that each DD value is related and linear with NASA-TLX WWL as presented on figure 5.3. It shows that DD can be considered as representation of the workload felt by the APP Controller due to the complexity of encountered traffic, and relatively have same pattern with the NASA-TLX WWL. Furthermore based on the result, basically the value of DD can be classified into ‘low’ until ‘high’ of workload category as NASA-TLX. But obviously it will be better and sufficient the data needed if the number of APP Controller observed is increased.

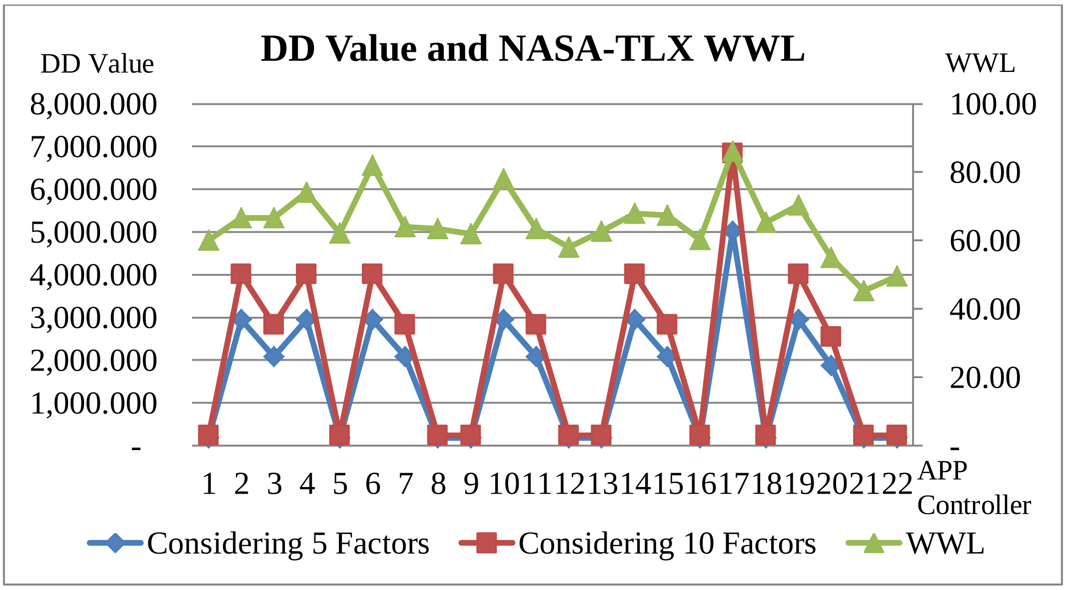

Figure 5.3 DD Value and NASA-TLX WWL

5.3 Improvement Suggestions Regarding AirNav Juanda APP Controller Workload

Considering significant factors which significantly affect the complexity and workload experienced by the APP Controller, suggestion of system improvement can be addressed to complexity factors and problems which mostly happened. The highest value portion of factors in DD_5 is SV, then the approach to solve this problem is by divide the sector volume into a new sector. But this solution is admitted as very expensive by AirNav Juanda management and need detailed feasibility study which takes long time of analysis. After SV, there are separation issues and velocity variation as APP Controller workload triggering factors. Therefore the improvement suggestions should consider separation and speed variation factors in purpose to lowering the workload value of APP Controller.

The improvement suggestions regarding AirNav Juanda APP Controller workload which considering aircraft separation and speed variation are listed in the following page:

- Air Traffic Density and Aircraft Separation Management

  Aircraft separation cannot be exactly determined because the aircraft velocity adjusted by the pilot depends on its load-carried weight and air space condition at that time (such as terrain existence, wind direction, bad weather, etc.). But APP Controller has authority to guide the aircraft velocity and adjust its altitude. Aircraft is allowed to cruise with less than 5 NMs of separation when it has 1000ft different altitude towards another aircraft, therefore the altitude adjustment is commonly used by APP Controller as easiest and fastest approach to maintain aircraft in tolerable separation.

  Based on expert judgment, minimum separation commonly happened when the traffic crowded. The unfortunate consideration is when the piling traffic crowd is triggered by indiscipline of parties involved in the provision of air transport services which mainly affect the schedule. Traffic can be piled at certain time because of aircraft delay. The delay concerned in this case is caused by technical problem from airline internal scope, facilities provider (airport, ground handling, maintenance facility, etc.), or AirNav readiness itself. Therefore, the technical problem that basically can be controlled should be smoothly conducted. It is purposed to avoid the controllable factor become a trigger of the traffic piling. In purpose to ensure the smoothness of controllable factor, traffic management should give more rewards for those who has good achievements, and strict punishment or penalty to whom violate the standards.

- Supporting Facilities Management

  Basically, the problem with respect to the workload arisen by the minimum separation is intense communication demand in order to avoid aircraft collision. It is sometimes exacerbated by bad communication due to poorly maintained facilities or even due to installation of new communication devices. Obviously at the beginning, the APP Controller not familiar with the devices change, whereas APP Controller has to make a decision in a very limited of time (the controller must response within 3 seconds). In purpose to minimize negative aspects generated by installment of new technology, a bottom-up discussion should be conducted in the device selection and supplemented by adequate training for all APP Controller.

- Internal and External Relationship Management

  In macro-ergonomics concept, good relationship between APP Controllers either toward management are very important. The good relationship also determines the controllers' performance quality and workload burdened on them. Therefore, the establishment of interpersonal relationship in AirNav is very important. Even a regular gathering should be held.

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6. CHAPTER VI
CONCLUSIONS AND RECOMMENDATIONS

This chapter consists of this research conclusions and recommendations. Therefore, the following research can be better executed.

6.1 Conclusions

According to the research that has been conducted, the conclusions can be inferred as follow:

1. Every airspace has different condition, it makes the significant level of every complexity factor is also different between airspaces. Based on AirNav Juanda expert judgment, the DD complexity factors significant level is obtained by using AHP. By considering AHP that conducted in stages toward each set of complexity factors, the sequence of 5 factors (DD_5) and 10 factors consideration (DD_{10}) are obtained. The factor sequence for DD_5 is: 1) number of aircraft with 3-D Euclidian distance between 0-5 NM (S5), 2) number of aircraft with predicted horizontal separation under 8 NM (NUMHORIZ), 3) separation critically index (SCI), 4) sector volume (SV) and 5) ratio of standard deviation of speed to average speed (C15). While for DD_{10} is: 1) S5, 2) NUMHORIZ, 3) SCI, 4) SV, 5) C15, 6) aircraft count (AC), 7) count of number aircraft within a threshold distance of a sector boundary (e.g., 20 NM) (WB PROX), 8) horizontal proximity (C9), 9) aircraft density (AD1) and 10) number of aircraft with 3-D Euclidian distance between 5-10 NM (S10).
2. Representation of workload burdened to AirNav Juanda APP Controller, especially in May 2017, is 9.1% ‘very high’, 81.8% ‘high’ and 9.1% ‘medium-high’. From the traffic-pictures observation, every detailed complexity value of each factor can be generated. Then the DD value is compared with WWL to obtain comparison-pattern which shows these complexity factors influence APP Controller workload level.

3. By using linear regression analysis, complexity factors of DD_5 and DD_{10} are defined has significant relationship (influence) toward APP Controller WWL. The R^2 for this statement is about 0.605. It is also found that R^2 of DD_{10} is relatively similar with DD_5, which means that 5 highest factors already represent most of the complexity factors which determine the AirNav Juanda APP Controller workload.
4. Complexity factors in DD_5 structured of 3 separation factors, 1 speed variation and 1 sector volume. The variation of separation issues have biggest weighting factors based on expert judgment, therefore the solution suggested is focused to minimize the separation issues. The suggestions are: 1) Reward event for employee with good achievement and punishment for violation from the management; 2) Ensure good communication device and its supporting handling skills by doing bottom-up discussion and adequate training and 3) Regular gathering to maintain good relationship between operators and employees.

6.2 Recommendations

To improve future research, some recommendations are listed below:

1. A particular research phase focusing on complexity factors of observed airports authorized airspaces should be held. In the Juanda Airport case, authorized airspaces under APP are TMAW, TMAE and Director Sector.
2. Since DD assessment result can be validated by using NASA-TLX, preferably in further research the number of APP Controller observed can be increased to meet data requirement. So the future DD value can be classified as NASA-TLX workload classification.
3. Advisably, an air traffic simulation can be generated on the following research. The simulation can be made manually, or by installing BEST RADAR Software to AirNav surveillance processor. The simulation can be used to design several scenarios of the air traffic, so the research can be conducted anytime. Moreover, developing the simulation will ease calculation and ensure a proper system development scenario in reducing the ATC workload before it is actually applied to the work station.

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GLOSSARY

Air Traffic Controller (ATC)	A person in charge to maintain and control air traffic in a specified area.
Analytical Hierarchy Process (AHP)	A supporting decision making tool which part of MCDM. This model is used to constrict multi-factor and multi-criteria into one hierarchy to define the weighting between each alternative.
ATC Intent (CI)	Specific action taken by ATC depending on the motivation.
Control Area (CTA)	Authorized airspace higher than 24,500ft.
Control Zone (CTR)	Authorized airspace starts from terrain surface until 10,000ft.
Dynamic Density (DD)	A workload assessment approach by mainly considering its traffic complexity and density.
Federal Aviation Administration (FAA)	A United States department of civil aviation which part of Transportation Ministry. Its regulations are commonly become the orientation of civil aviation in the other countries.
Flight Information Region (FIR)	All ATC authorized airspace in certain country.

Instrument Flight Rules (IFR)	Set of regulations in bad weather when a pilot hard to determine surrounding condition under visualization orientation.
Juanda Approach Unit (APP)	One of two service units of AirNav Juanda which assigned to provides control service by using surveillance. Its working altitude starts from terrain-24,500ft.
Juanda Tower Unit (TWR)	One of two service units of AirNav Juanda which assigned to provides control service from Juanda Airport Tower by using the controller direct visual availability. Its working altitude starts from terrain-2,000ft.
Multi Criteria Decision Making (MCDM)	A decision making approach by determining the best option between several alternatives based on some defined criterion.
NASA Task Load Index (NASA-TLX)	A method developed by NASA to measure mental workload.
Nautical Miles (NM)	A length measurement unit which equals to 1,852 meter.
Non Directional Beacon (NDB)	Simple radio air traffic sign without radio beacon as minimum navigation requirement of airport. This tool helps pilot to know the position of an airport by spreading radio

	signal to all direction. (Not operated anymore in Juanda Airport)
Secondary Surveillance Radar (SSR)	Radar system used by ATC to detect, measure and communicate with flying aircraft. This device is installed on the aircraft and also can be used by pilot to find closer airports.
Space-Based Radar (SBR)	Radar used by airport to obtain information about terrain and land-cover.
Terminal Maneuvering Area (TMA)	Airspace area which starts from 10,000 until 24,500ft.
Traffic Complexity (TC)	Mixture of several factors in one time in an air traffic.
Traffic Density (TD)	Volume of aircraft in a volume of airspace.
Visual Flight Rules (VFR)	Set of regulations in clear enough weather condition when a pilot able to see where the aircraft is going. It helps the pilot to confidently determine terrain, signs, and other condition under visual orientation.
VOR/DME	Combination of radio navigation station which consists of VHF Omnidirectional Range (VOR) and Distance Measuring Equipment (DME). Together, they provide navigational chart.

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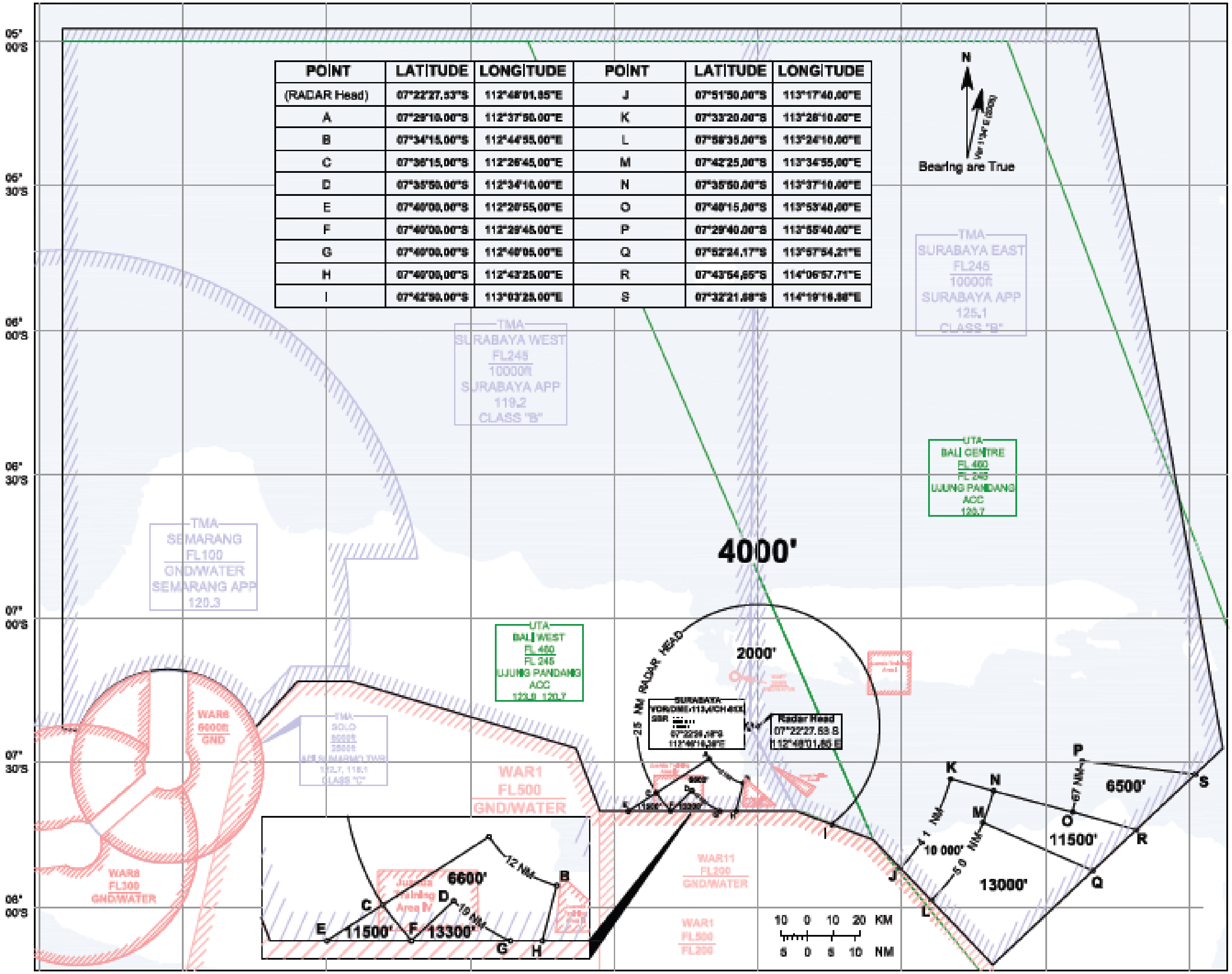
APPENDIX 1



POINT	LATITUDE	LONGITUDE	POINT	LATITUDE	LONGITUDE
(RADAR Head)	07°22'27.53"S	112°48'01.85"E	J	07°51'50,00"S	113°17'40,00"E
A	07°29'10,00"S	112°37'50,00"E	K	07°33'20,00"S	113°28'10,00"E
B	07°34'15,00"S	112°44'55,00"E	L	07°58'35,00"S	113°24'10,00"E
C	07°36'15,00"S	112°26'45,00"E	M	07°42'25,00"S	113°34'55,00"E
D	07°35'50,00"S	112°34'10,00"E	N	07°35'50,00"S	113°37'10,00"E
E	07°40'00,00"S	112°20'55,00"E	O	07°40'15,00"S	113°53'40,00"E
F	07°40'00,00"S	112°29'45,00"E	P	07°29'40,00"S	113°55'40,00"E
G	07°40'00,00"S	112°40'05,00"E	Q	07°52'24,17"S	113°57'54,21"E
H	07°40'00,00"S	112°43'25,00"E	R	07°43'54,65"S	114°06'57.71"E
I	07°42'50,00"S	113°03'25,00"E	S	07°32'21,88"S	114°19'16,86"E

APPENDIX 2

AHP of weighting factors of 17 DD complexity factors: Expert judgment based on experienced ATC response.

AHP of 17 Complexity Factors	AD1	SCI	SV	AC	C2	C9	C11	C15	C16	S5	S10	WCON VANG	WB PROX	WASP	NUMH ORIZ	HDG VARI	AXIS HDG
AD1	1	0.2	0.14	5	5	5	5	0.14	5	0.14	5	5	0.14	5	0.2	0.2	5
SCI	5	1	1	0.2	5	1	5	5	1	0.14	1	5	5	5	1	3	5
SV	7	1	1	5	5	5	5	1	5	0.14	3	5	1	0.2	0.14	1	0.2
AC	0.2	5	0.2	1	3	5	5	0.2	5	0.14	3	5	0.2	5	0.14	0.2	5
C2	0.2	0.2	0.2	0.33	1	0.33	3	0.2	1	0.14	0.2	1	0.2	1	0.2	1	1
C9	0.2	1	0.2	0.2	3	1	5	0.2	3	0.14	0.2	3	1	5	7	5	5
C11	0.2	0.2	0.2	0.2	0.33	0.2	1	0.14	0.2	5	0.2	0.2	0.33	1	0.2	0.2	1
C15	7	0.2	1	5	5	5	7	1	5	0.14	1	5	1	5	0.14	7	5
C16	0.2	1	0.2	0.2	1	0.33	5	0.2	1	0.14	0.33	1	0.2	1	0.2	1	1
S5	7	7	7	7	7	7	0.2	7	7	1	7	7	7	7	7	7	7
S10	0.2	1	0.33	0.33	5	5	5	1	3	0.14	1	5	1	5	0.2	5	5
WCONVANG	0.2	0.2	0.2	0.2	1	0.33	5	0.2	1	0.14	0.2	1	0.2	1	0.2	1	1
WB PROX	7	0.2	1	5	5	1	3	1	5	0.14	1	5	1	1	1	5	1
WASP	0.2	0.2	5	0.2	1	0.2	1	0.2	1	0.14	0.2	1	1	1	0.2	0.33	1
NUMHORIZ	5	1	7	7	5	0.14	5	7	5	0.14	5	5	1	5	1	5	5
HDG VARI	5	0.33	1	5	1	0.2	5	0.14	1	0.14	0.2	1	0.2	3	0.2	1	3
AXIS HDG	0.2	0.2	5	0.2	1	0.2	1	0.2	1	0.14	0.2	1	1	1	0.2	0.33	1
Total	**45.80**	**19.93**	**30.68**	**42.07**	**54.33**	**36.94**	**66.20**	**24.83**	**50.20**	**8.14**	**28.73**	**56.20**	**21.48**	**52.20**	**19.23**	**43.27**	**52.20**

AHP of weighting factors of 17 DD complexity factors: AHP value based on expert judgment.

AHP of 17 Complexity Factors	AD1	SCI	SV	AC	C2	C9	C11	C15	C16	S5	S10	WCON VANG	WB PROX	WASP	NUMH ORIZ	HDG VARI	AXIS HDG	Average (Weight)	Rank
AD1	0.02	0.01	0.00	0.12	0.09	0.14	0.08	0.01	0.10	0.02	0.17	0.09	0.01	0.10	0.01	0.00	0.10	0.06	8
SCI	0.11	0.05	0.03	0.00	0.09	0.03	0.08	0.20	0.02	0.02	0.03	0.09	0.23	0.10	0.05	0.07	0.10	0.08	4
SV	0.15	0.05	0.03	0.12	0.09	0.14	0.08	0.04	0.10	0.02	0.10	0.09	0.05	0.00	0.01	0.02	0.00	0.06	5
AC	0.00	0.25	0.01	0.02	0.06	0.14	0.08	0.01	0.10	0.02	0.10	0.09	0.01	0.10	0.01	0.00	0.10	0.06	7
C2	0.00	0.01	0.01	0.01	0.02	0.01	0.05	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.02	0.01	17
C9	0.00	0.05	0.01	0.00	0.06	0.03	0.08	0.01	0.06	0.02	0.01	0.05	0.05	0.10	0.36	0.12	0.10	0.06	6
C11	0.00	0.01	0.01	0.00	0.01	0.01	0.02	0.01	0.00	0.61	0.01	0.00	0.02	0.02	0.01	0.00	0.02	0.04	11
C15	0.15	0.01	0.03	0.12	0.09	0.14	0.11	0.04	0.10	0.02	0.03	0.09	0.05	0.10	0.01	0.16	0.10	0.08	3
C16	0.00	0.05	0.01	0.00	0.02	0.01	0.08	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.02	0.02	15
S5	0.15	0.35	0.23	0.17	0.13	0.19	0.00	0.28	0.14	0.12	0.24	0.12	0.33	0.13	0.36	0.16	0.13	0.19	1
S10	0.00	0.05	0.01	0.01	0.09	0.14	0.08	0.04	0.06	0.02	0.03	0.09	0.05	0.10	0.01	0.12	0.10	0.06	10
WCONVANG	0.00	0.01	0.01	0.00	0.02	0.01	0.08	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.02	0.02	16
WB PROX	0.15	0.01	0.03	0.12	0.09	0.03	0.05	0.04	0.10	0.02	0.03	0.09	0.05	0.02	0.05	0.12	0.02	0.06	9
WASP	0.00	0.01	0.16	0.00	0.02	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.05	0.02	0.01	0.01	0.02	0.02	13
NUMHORIZ	0.11	0.05	0.23	0.17	0.09	0.00	0.08	0.28	0.10	0.02	0.17	0.09	0.05	0.10	0.05	0.12	0.10	0.11	2
HDG VARI	0.11	0.02	0.03	0.12	0.02	0.01	0.08	0.01	0.02	0.02	0.01	0.02	0.01	0.06	0.01	0.02	0.06	0.04	11
AXIS HDG	0.00	0.01	0.16	0.00	0.02	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.05	0.02	0.01	0.01	0.02	0.02	13
																	Total	**1.00**	

AHP of weighting factors of 5 DD complexity factors: AHP value based on expert judgment.

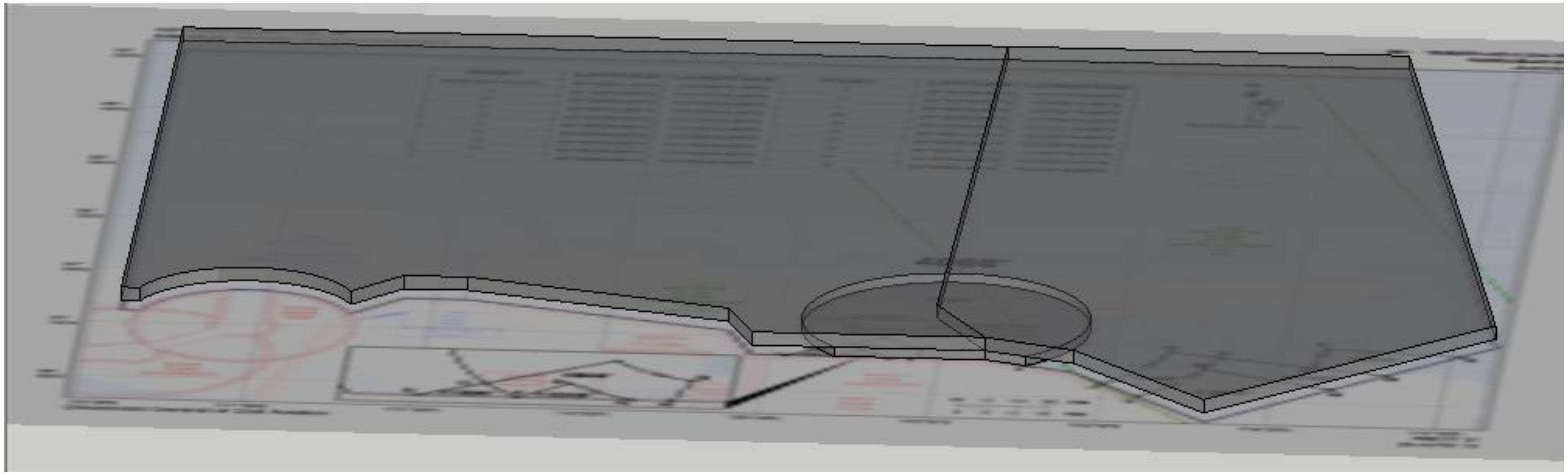
AHP of 5 Complexity Factors	SCI	SV	C15	S5	NUMHO RIZ	Average (Weight)	Rank
SCI	0.10	0.06	0.24	0.09	0.11	0.12	3
SV	0.10	0.06	0.05	0.09	0.02	0.06	4
C15	0.02	0.06	0.05	0.09	0.02	0.05	5
S5	0.69	0.41	0.33	0.64	0.75	0.56	1
NUMHORIZ	0.10	0.41	0.33	0.09	0.11	0.21	2
Total						**1.00**	

AHP of weighting factors of 10 DD complexity factors: AHP value based on expert judgment.

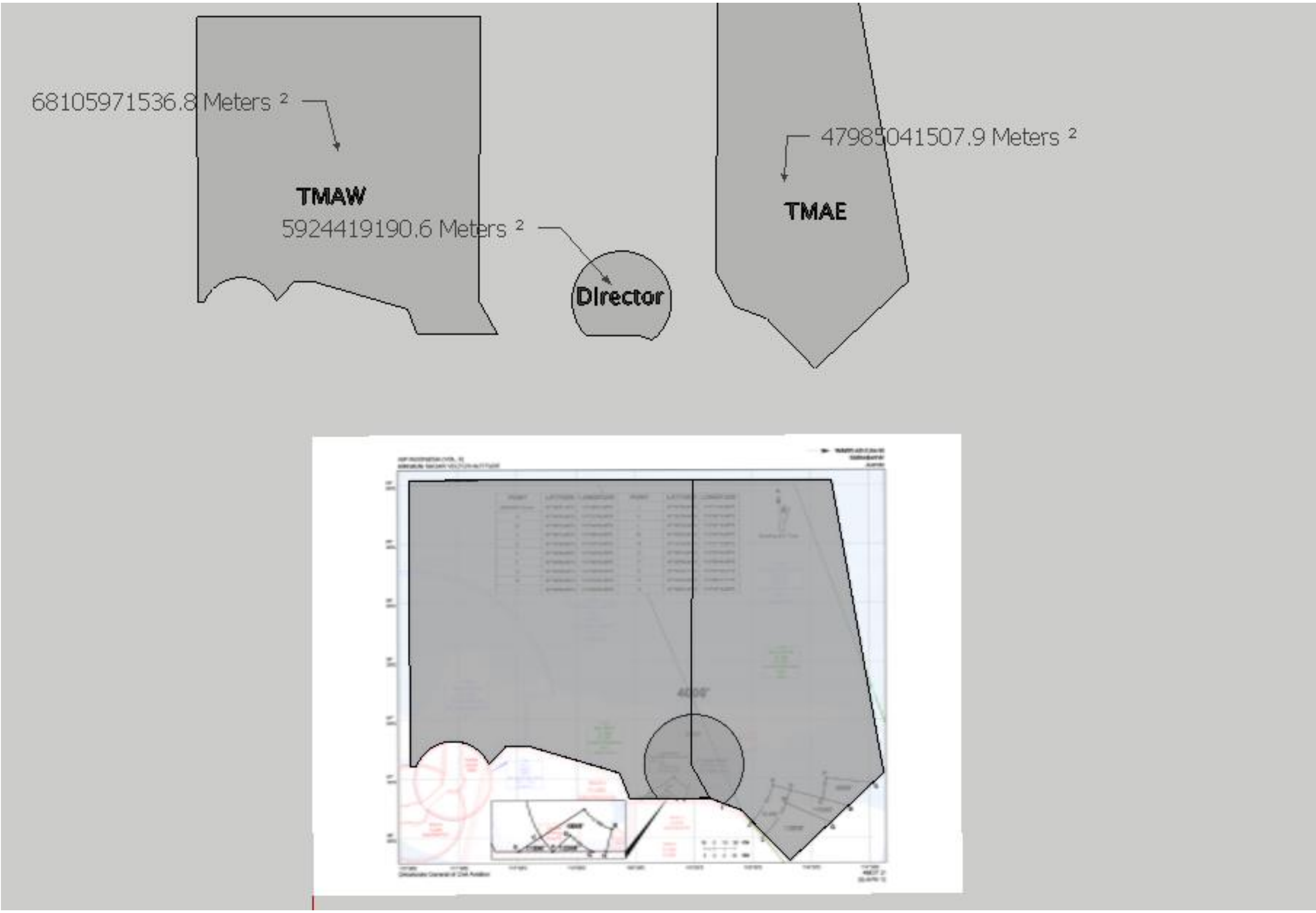
AHP of 10 Complexity Factors	AD1	SCI	SV	AC	C9	C15	S5	S10	WB PROX	NUMHORIZ	Average (weight)	Rank
AD1	0.03	0.01	0.01	0.14	0.14	0.01	0.06	0.18	0.01	0.01	0.060	9
SCI	0.13	0.06	0.05	0.01	0.03	0.21	0.06	0.04	0.27	0.06	0.091	3
SV	0.18	0.06	0.05	0.14	0.14	0.04	0.06	0.11	0.05	0.01	0.085	4
AC	0.01	0.28	0.01	0.03	0.14	0.01	0.06	0.11	0.01	0.01	0.067	6
C9	0.01	0.06	0.01	0.01	0.03	0.01	0.06	0.01	0.05	0.39	0.063	8
C15	0.18	0.01	0.05	0.14	0.14	0.04	0.06	0.04	0.05	0.01	0.073	5
S5	0.18	0.40	0.37	0.20	0.20	0.30	0.44	0.26	0.38	0.39	0.311	1
S10	0.01	0.06	0.02	0.01	0.14	0.04	0.06	0.04	0.05	0.01	0.044	10
WB PROX	0.18	0.01	0.05	0.14	0.03	0.04	0.06	0.04	0.05	0.06	0.066	7
NUMHORIZ	0.13	0.06	0.37	0.20	0.00	0.30	0.06	0.18	0.05	0.06	0.141	2
Total											**1.00**	

APPENDIX 3

3D visualization of AirNav Juanda authorized airspace.

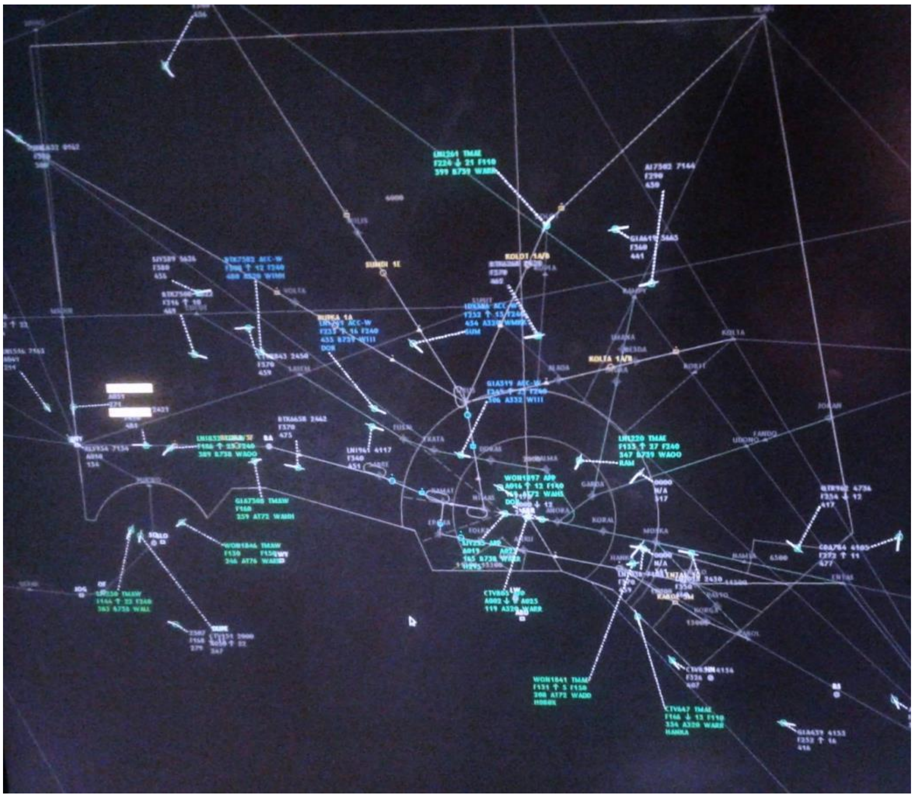


Top view of AirNav Juanda authorized airspace and its sectors.



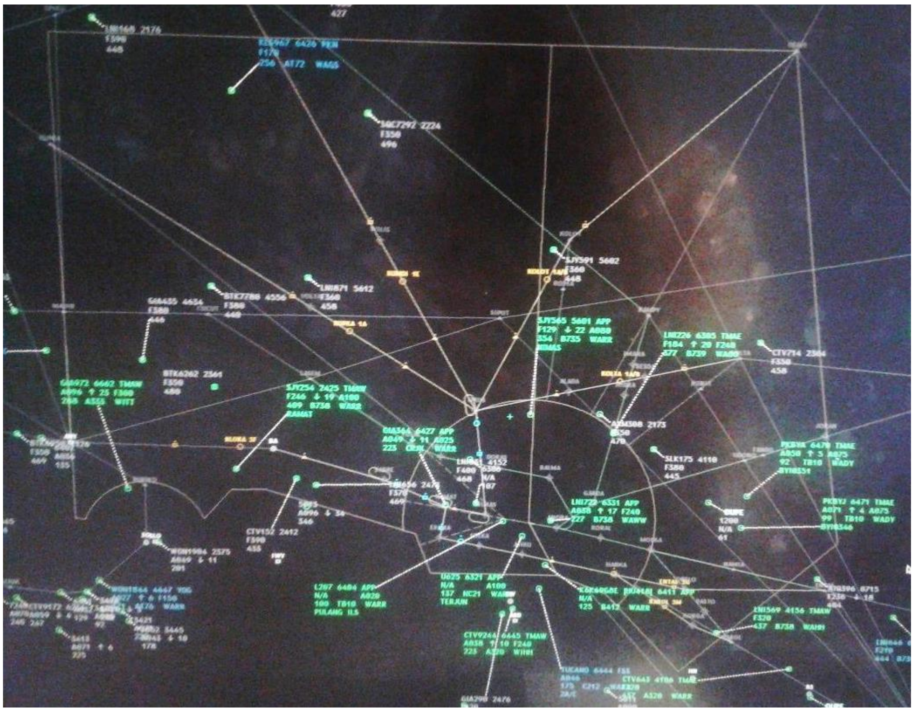
APPENDIX 4

1st round of 70-minutes Juanda air traffic at 15.50 UTC +7 of 2nd May 2017.

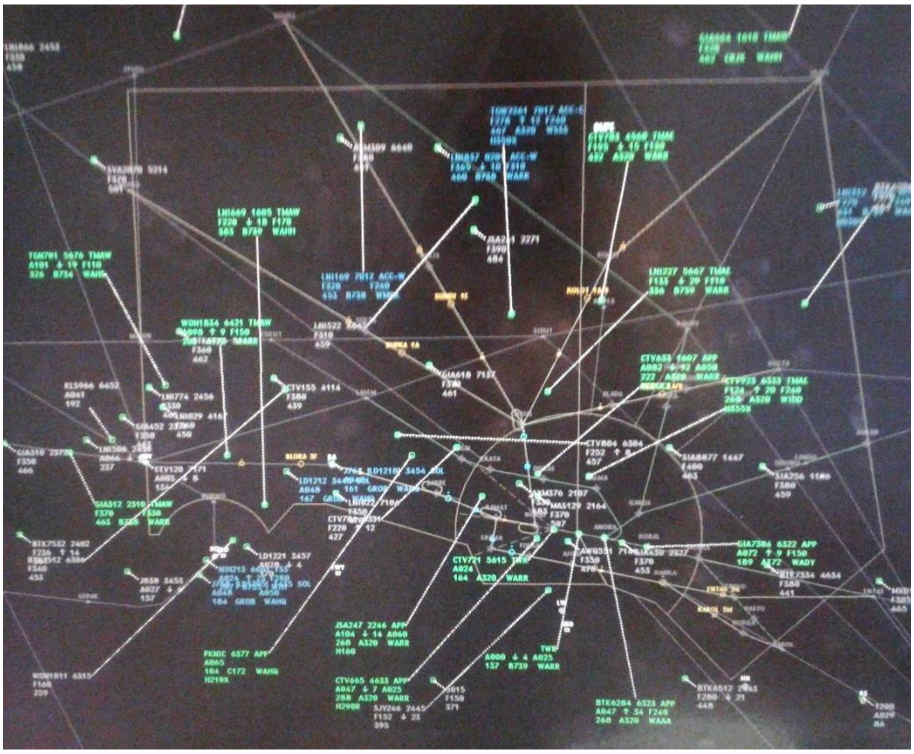


2nd round of 70-minutes Juanda air traffic at 09.25 UTC +7 of 3rd May 2017.

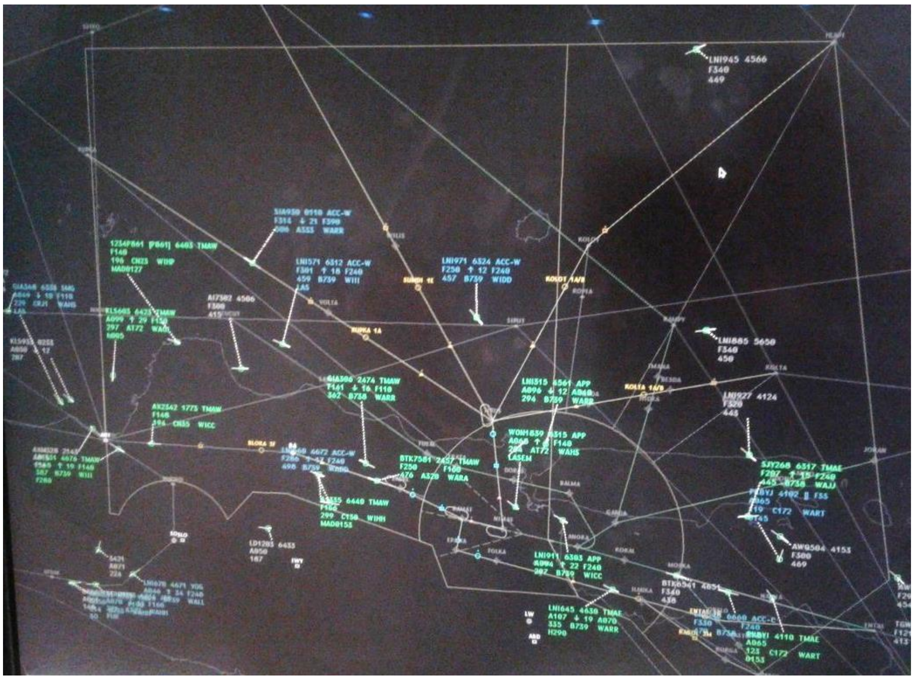
3rd round of 70-minutes Juanda air traffic at 09.55 UTC +7 of 4^{4h} May 2017.



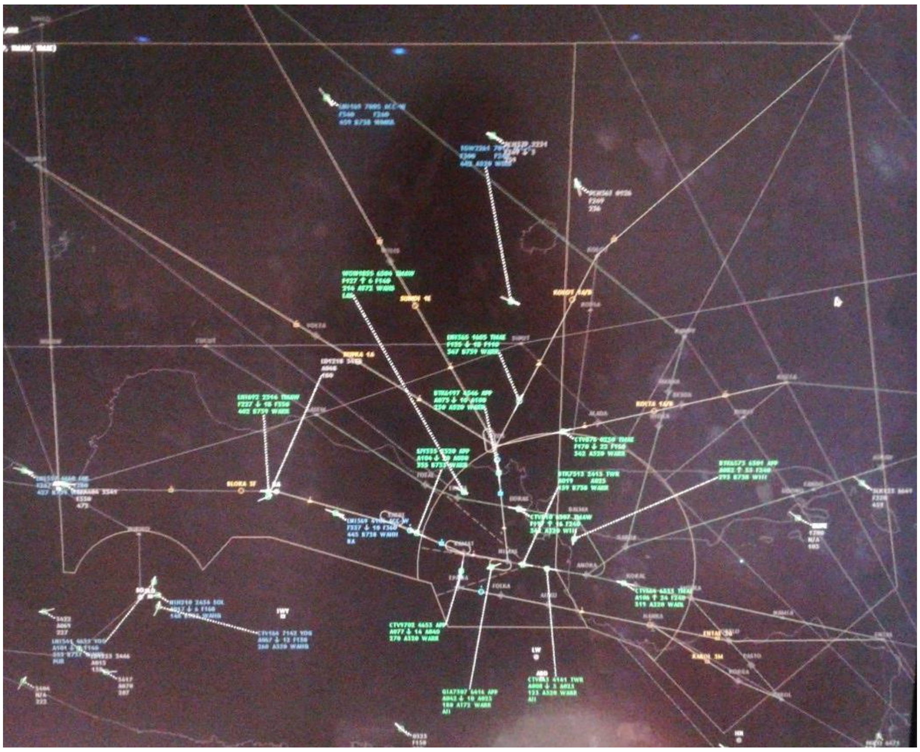
4th round of 70-minutes Juanda air traffic at 12.15 UTC +7 of 4^{4h} May 2017.



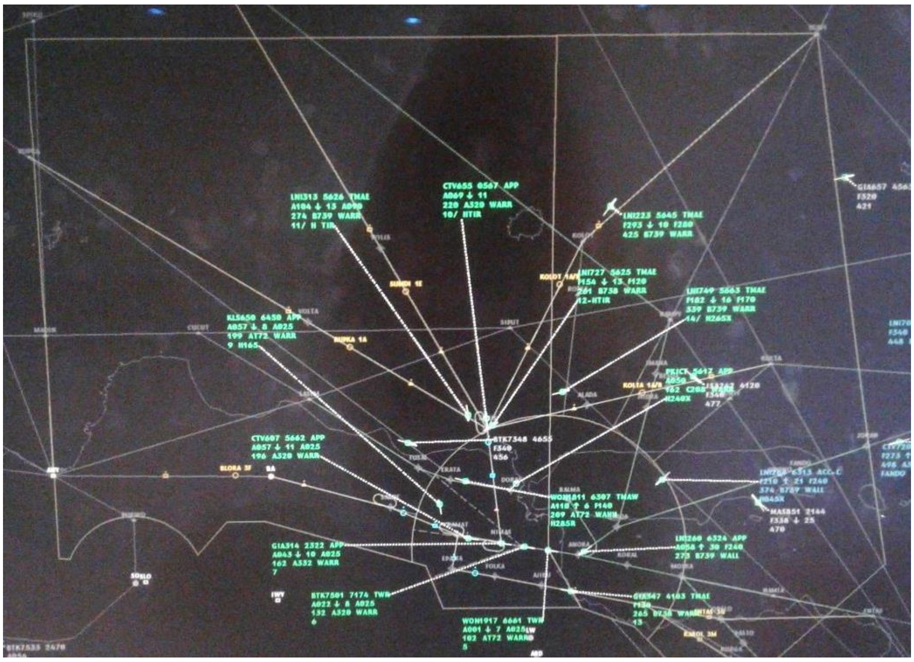
5^{th} round of 70-minutes Juanda air traffic at 08.30 UTC +7 of 5^{4h} May 2017.



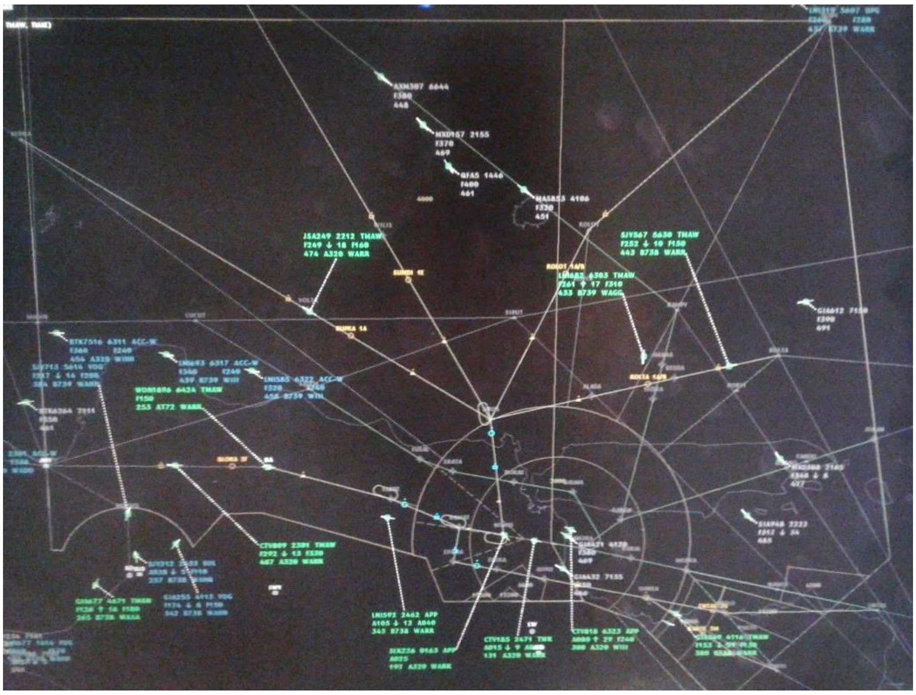
6^{th} round of 70-minutes Juanda air traffic at 10.55 UTC +7 of 5^{4h} May 2017.



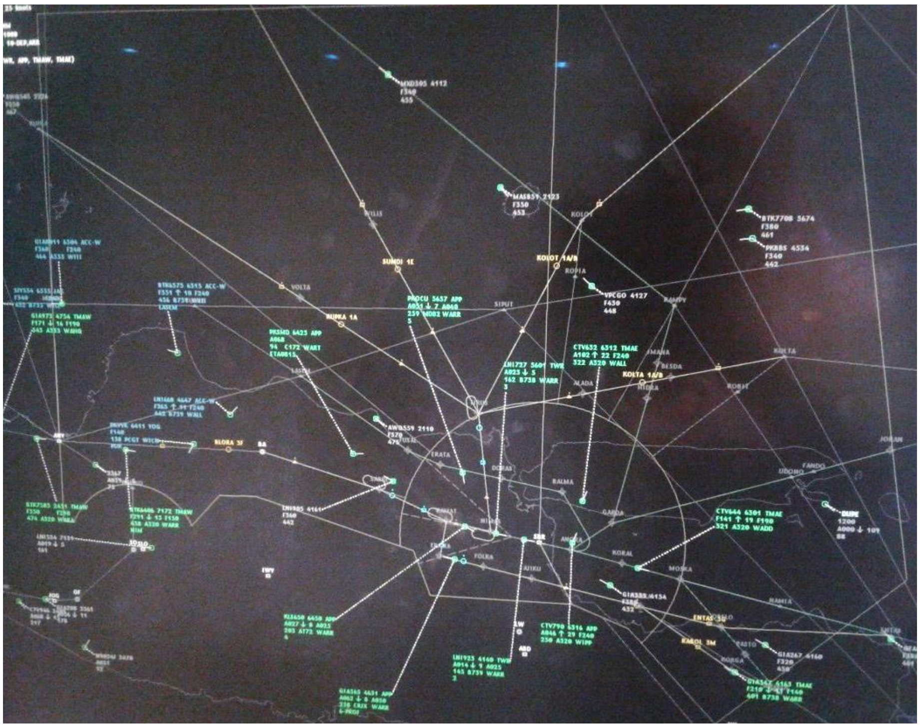
7th round of 70-minutes Juanda air traffic at 14.10 UTC +7 of 5th May 2017.



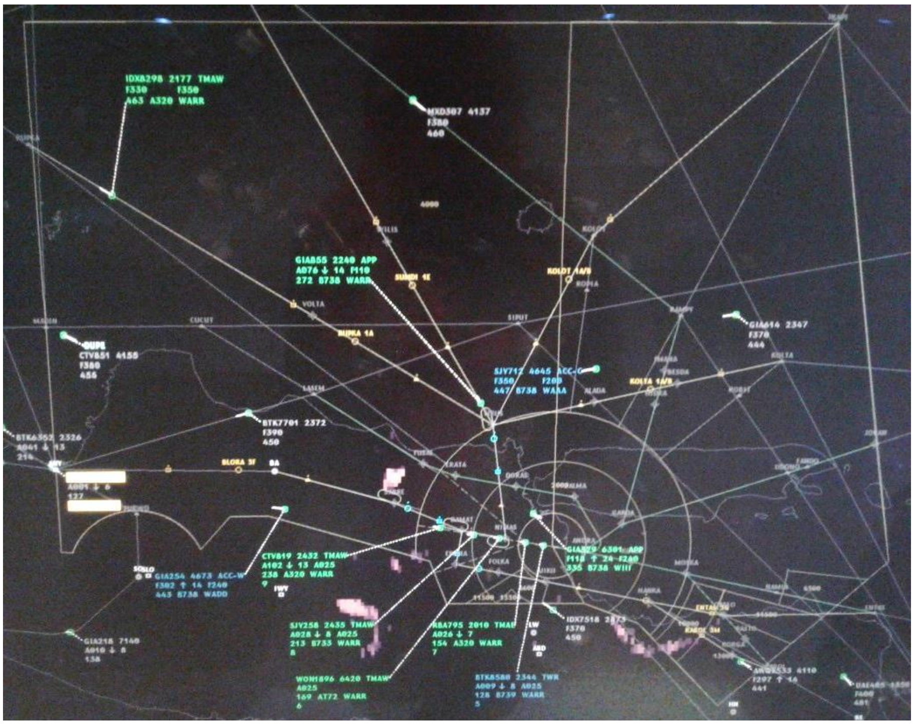
8th round of 70-minutes Juanda air traffic at 19.15 UTC +7 of 6th May 2017.



9^{th} round of 70-minutes Juanda air traffic at 14.20 UTC +7 of 10^{4h} May 2017.



10^{th} round of 70-minutes Juanda air traffic at 19.10 UTC +7 of 29^{4h} May 2017.



11th round of 70-minutes Juanda air traffic at 21.15 UTC +7 of 29[4h] May 2017.

APPENDIX 5

Complexity factors average and DD value of each APP Controller

APP Controller	Shift	Observation Time (UTC+7)	Sector	DD Complexity Factors									
				S5	NUMHO RIZ	SCI	SV	C15	AC	WB PROX	C9	AD1	S10
1	Day	15.30-16.20	Director	0.000	0.113	0.044	240.183	0.018	0.188	0.113	0.004	0.0000020	0.035
2	Day	15.30-16.20	TMAW	0.000	0.028	0.017	4011.485	0.011	0.208	0.159	0.003	0.0000022	0.009
3	Day	15.30-16.20	TMAE	0.000	0.000	0.003	2826.349	0.006	0.094	0.079	0.001	0.0000010	0.000
4	Morning	09.20-10.30	TMAW	0.000	0.082	0.000	4011.485	0.025	0.285	0.270	0.006	0.0000030	0.033
5	Morning	09.20-10.30	Director	0.000	0.117	0.096	240.183	0.019	0.285	0.243	0.005	0.0000030	0.051
6	Morning	09.20-10.30	TMAW	0.000	0.070	0.000	4011.485	0.023	0.251	0.232	0.004	0.0000027	0.022
7	Morning	09.20-10.30	TMAE	0.000	0.035	0.000	2826.349	0.025	0.201	0.165	0.003	0.0000021	0.026
8	Morning	09.20-10.30	Director	0.052	0.258	0.106	240.183	0.030	0.391	0.320	0.017	0.0000042	0.095
9	Morning	11.40-13.00	Director	0.000	0.156	0.108	240.183	0.026	0.290	0.279	0.006	0.0000031	0.068
10	Morning	11.40-13.00	TMAW	0.000	0.047	0.000	4011.485	0.022	0.276	0.184	0.003	0.0000029	0.039
11	Morning	08.10-09.20	TMAE	0.000	0.000	0.000	2826.349	0.011	0.140	0.096	0.002	0.0000015	0.000
12	Morning	08.10-09.21	Director	0.000	0.090	0.025	240.183	0.026	0.195	0.126	0.004	0.0000021	0.028
13	Morning	10.30-11.40	Director	0.085	0.128	0.115	240.183	0.015	0.280	0.265	0.010	0.0000030	0.068
14	Day	13.00-14.10	TMAW	0.000	0.000	0.000	4011.485	0.009	0.097	0.088	0.000	0.0000010	0.000
15	Day	13.00-14.10	TMAE	0.000	0.078	0.000	2826.349	0.022	0.283	0.265	0.004	0.0000030	0.024
16	Day	13.00-14.10	Director	0.000	0.156	0.111	240.183	0.011	0.253	0.235	0.004	0.0000027	0.058
17	Night	19.00-20.10	TMAW&E	0.000	0.014	0.000	6837.834	0.014	0.328	0.258	0.004	0.0000035	0.053
18	Night	19.00-20.10	Director	0.000	0.084	0.013	240.183	0.011	0.168	0.165	0.003	0.0000018	0.039
19	Day	14.20-15.30	TMAW	0.000	0.031	0.000	4011.485	0.012	0.223	0.213	0.002	0.0000024	0.015
20	Day	14.20-15.30	TMAE	0.000	0.000	0.002	2538.997	0.014	0.290	0.257	0.003	0.0000031	0.000
21	Night	19.00-20.10	Director	0.000	0.012	0.007	240.183	0.009	0.134	0.121	0.003	0.0000014	0.011
22	Night	20.10-21.20	Director	0.000	0.084	0.000	240.183	0.017	0.161	0.113	0.004	0.0000017	0.039

DD_5 Value

APP Controller	Shift	Observation Time (UTC+7)	Sector	DD Complexity Factors					5 Factors
				S5	NUMHORIZ	SCI	SV	C15	
1	Day	15.30-16.20	Director	0.000	0.167	0.058	176.343	0.012	176.579
2	Day	15.30-16.20	TMAW	0.000	0.042	0.022	2945.249	0.007	2945.320
3	Day	15.30-16.20	TMAE	0.000	0.000	0.003	2075.117	0.004	2075.125
4	Morning	09.20-10.30	TMAW	0.000	0.122	0.000	2945.249	0.016	2945.386
5	Morning	09.20-10.30	Director	0.000	0.174	0.125	176.343	0.012	176.654
6	Morning	09.20-10.30	TMAW	0.000	0.104	0.000	2945.249	0.014	2945.367
7	Morning	09.20-10.30	TMAE	0.000	0.052	0.000	2075.117	0.016	2075.185
8	Morning	09.20-10.30	Director	0.094	0.382	0.138	176.343	0.019	176.976
9	Morning	11.40-13.00	Director	0.000	0.231	0.141	176.343	0.017	176.732
10	Morning	11.40-13.00	TMAW	0.000	0.069	0.000	2945.249	0.014	2945.332
11	Morning	08.10-09.20	TMAE	0.000	0.000	0.000	2075.117	0.007	2075.124
12	Morning	08.10-09.21	Director	0.000	0.133	0.033	176.343	0.016	176.525
13	Morning	10.30-11.40	Director	0.154	0.189	0.150	176.343	0.010	176.847
14	Day	13.00-14.10	TMAW	0.000	0.000	0.000	2945.249	0.006	2945.255
15	Day	13.00-14.10	TMAE	0.000	0.116	0.000	2075.117	0.014	2075.247
16	Day	13.00-14.10	Director	0.000	0.231	0.145	176.343	0.007	176.727
17	Night	19.00-20.10	TMAW&E	0.000	0.021	0.000	5020.366	0.009	5020.396
18	Night	19.00-20.10	Director	0.000	0.125	0.017	176.343	0.007	176.492
19	Day	14.20-15.30	TMAW	0.000	0.046	0.000	2945.249	0.008	2945.303
20	Day	14.20-15.30	TMAE	0.000	0.000	0.002	1864.142	0.009	1864.153
21	Night	19.00-20.10	Director	0.000	0.017	0.010	176.343	0.006	176.376
22	Night	20.10-21.20	Director	0.000	0.125	0.000	176.343	0.011	176.479
				Max	5020.396	Avg	1573.799	Min	176.376

DD$_{10}$ Value

APP Controller	Shift	Observation Time (UTC+7)	Sector	DD Complexity Factors										10 Factors
				S5	NUMHORIZ	SCI	SV	C15	AC	WB PROX	C9	AD1	S10	
1	Day	15.30-16.20	Director	0.000	0.113	0.044	240.183	0.018	0.188	0.113	0.004	0.0000020	0.035	240.698
2	Day	15.30-16.20	TMAW	0.000	0.028	0.017	4011.485	0.011	0.208	0.159	0.003	0.0000022	0.009	4011.919
3	Day	15.30-16.20	TMAE	0.000	0.000	0.003	2826.349	0.006	0.094	0.079	0.001	0.0000010	0.000	2826.532
4	Morning	09.20-10.30	TMAW	0.000	0.082	0.000	4011.485	0.025	0.285	0.270	0.006	0.0000030	0.033	4012.186
5	Morning	09.20-10.30	Director	0.000	0.117	0.096	240.183	0.019	0.285	0.243	0.005	0.0000030	0.051	240.999
6	Morning	09.20-10.30	TMAW	0.000	0.070	0.000	4011.485	0.023	0.251	0.232	0.004	0.0000027	0.022	4012.087
7	Morning	09.20-10.30	TMAE	0.000	0.035	0.000	2826.349	0.025	0.201	0.165	0.003	0.0000021	0.026	2826.804
8	Morning	09.20-10.30	Director	0.052	0.258	0.106	240.183	0.030	0.391	0.320	0.017	0.0000042	0.095	241.452
9	Morning	11.40-13.00	Director	0.000	0.156	0.108	240.183	0.026	0.290	0.279	0.006	0.0000031	0.068	241.117
10	Morning	11.40-13.00	TMAW	0.000	0.047	0.000	4011.485	0.022	0.276	0.184	0.003	0.0000029	0.039	4012.055
11	Morning	08.10-09.20	TMAE	0.000	0.000	0.000	2826.349	0.011	0.140	0.096	0.002	0.0000015	0.000	2826.598
12	Morning	08.10-09.21	Director	0.000	0.090	0.025	240.183	0.026	0.195	0.126	0.004	0.0000021	0.028	240.676
13	Morning	10.30-11.40	Director	0.085	0.128	0.115	240.183	0.015	0.280	0.265	0.010	0.0000030	0.068	241.149
14	Day	13.00-14.10	TMAW	0.000	0.000	0.000	4011.485	0.009	0.097	0.088	0.000	0.0000010	0.000	4011.679
15	Day	13.00-14.10	TMAE	0.000	0.078	0.000	2826.349	0.022	0.283	0.265	0.004	0.0000030	0.024	2827.025
16	Day	13.00-14.10	Director	0.000	0.156	0.111	240.183	0.011	0.253	0.235	0.004	0.0000027	0.058	241.013
17	Night	19.00-20.10	TMAW&E	0.000	0.014	0.000	6837.834	0.014	0.328	0.258	0.004	0.0000035	0.053	6838.505
18	Night	19.00-20.10	Director	0.000	0.084	0.013	240.183	0.011	0.168	0.165	0.003	0.0000018	0.039	240.667
19	Day	14.20-15.30	TMAW	0.000	0.031	0.000	4011.485	0.012	0.223	0.213	0.002	0.0000024	0.015	4011.981
20	Day	14.20-15.30	TMAE	0.000	0.000	0.002	2538.997	0.014	0.290	0.257	0.003	0.0000031	0.000	2539.564
21	Night	19.00-20.10	Director	0.000	0.012	0.007	240.183	0.009	0.134	0.121	0.003	0.0000014	0.011	240.480
22	Night	20.10-21.20	Director	0.000	0.084	0.000	240.183	0.017	0.161	0.113	0.004	0.0000017	0.039	240.601
									Max	6838.505	Avg	2143.899	Min	240.480

APPENDIX 6

Value portion of each factor in DD_5

APP Controller	Shift	Observation Time (UTC+7)	Sector	DD Complexity Factors				
				S5	NUMHORIZ	SCI	SV	C15
1	Day	15.30-16.20	Director	0.000	0.167	0.058	176.343	0.012
2	Day	15.30-16.20	TMAW	0.000	0.042	0.022	2945.249	0.007
3	Day	15.30-16.20	TMAE	0.000	0.000	0.003	2075.117	0.004
4	Morning	09.20-10.30	TMAW	0.000	0.122	0.000	2945.249	0.016
5	Morning	09.20-10.30	Director	0.000	0.174	0.125	176.343	0.012
6	Morning	09.20-10.30	TMAW	0.000	0.104	0.000	2945.249	0.014
7	Morning	09.20-10.30	TMAE	0.000	0.052	0.000	2075.117	0.016
8	Morning	09.20-10.30	Director	0.094	0.382	0.138	176.343	0.019
9	Morning	11.40-13.00	Director	0.000	0.231	0.141	176.343	0.017
10	Morning	11.40-13.00	TMAW	0.000	0.069	0.000	2945.249	0.014
11	Morning	08.10-09.20	TMAE	0.000	0.000	0.000	2075.117	0.007
12	Morning	08.10-09.21	Director	0.000	0.133	0.033	176.343	0.016
13	Morning	10.30-11.40	Director	0.154	0.189	0.150	176.343	0.010
14	Day	13.00-14.10	TMAW	0.000	0.000	0.000	2945.249	0.006
15	Day	13.00-14.10	TMAE	0.000	0.116	0.000	2075.117	0.014
16	Day	13.00-14.10	Director	0.000	0.231	0.145	176.343	0.007
17	Night	19.00-20.10	TMAW&E	0.000	0.021	0.000	5020.366	0.009
18	Night	19.00-20.10	Director	0.000	0.125	0.017	176.343	0.007
19	Day	14.20-15.30	TMAW	0.000	0.046	0.000	2945.249	0.008
20	Day	14.20-15.30	TMAE	0.000	0.000	0.002	1864.142	0.009
21	Night	19.00-20.10	Director	0.000	0.017	0.010	176.343	0.006
22	Night	20.10-21.20	Director	0.000	0.125	0.000	176.343	0.011
				Average				
				0.011	0.107	0.038	1573.632	0.011

Value portion of each factor in DD_{10}

APP Controller	Shift	Observation Time (UTC+7)	Sector	DD Complexity Factors									
				S5	**NUMHORIZ**	**SCI**	**SV**	**C15**	**AC**	**WB PROX**	**C9**	**AD1**	**S10**
1	Day	15.30-16.20	Director	0.000	0.113	0.044	240.183	0.018	0.188	0.113	0.004	0.0000020	0.035
2	Day	15.30-16.20	TMAW	0.000	0.028	0.017	4011.485	0.011	0.208	0.159	0.003	0.0000022	0.009
3	Day	15.30-16.20	TMAE	0.000	0.000	0.003	2826.349	0.006	0.094	0.079	0.001	0.0000010	0.000
4	Morning	09.20-10.30	TMAW	0.000	0.082	0.000	4011.485	0.025	0.285	0.270	0.006	0.0000030	0.033
5	Morning	09.20-10.30	Director	0.000	0.117	0.096	240.183	0.019	0.285	0.243	0.005	0.0000030	0.051
6	Morning	09.20-10.30	TMAW	0.000	0.070	0.000	4011.485	0.023	0.251	0.232	0.004	0.0000027	0.022
7	Morning	09.20-10.30	TMAE	0.000	0.035	0.000	2826.349	0.025	0.201	0.165	0.003	0.0000021	0.026
8	Morning	09.20-10.30	Director	0.052	0.258	0.106	240.183	0.030	0.391	0.320	0.017	0.0000042	0.095
9	Morning	11.40-13.00	Director	0.000	0.156	0.108	240.183	0.026	0.290	0.279	0.006	0.0000031	0.068
10	Morning	11.40-13.00	TMAW	0.000	0.047	0.000	4011.485	0.022	0.276	0.184	0.003	0.0000029	0.039
11	Morning	08.10-09.20	TMAE	0.000	0.000	0.000	2826.349	0.011	0.140	0.096	0.002	0.0000015	0.000
12	Morning	08.10-09.21	Director	0.000	0.090	0.025	240.183	0.026	0.195	0.126	0.004	0.0000021	0.028
13	Morning	10.30-11.40	Director	0.085	0.128	0.115	240.183	0.015	0.280	0.265	0.010	0.0000030	0.068
14	Day	13.00-14.10	TMAW	0.000	0.000	0.000	4011.485	0.009	0.097	0.088	0.000	0.0000010	0.000
15	Day	13.00-14.10	TMAE	0.000	0.078	0.000	2826.349	0.022	0.283	0.265	0.004	0.0000030	0.024
16	Day	13.00-14.10	Director	0.000	0.156	0.111	240.183	0.011	0.253	0.235	0.004	0.0000027	0.058
17	Night	19.00-20.10	TMAW&E	0.000	0.014	0.000	6837.834	0.014	0.328	0.258	0.004	0.0000035	0.053
18	Night	19.00-20.10	Director	0.000	0.084	0.013	240.183	0.011	0.168	0.165	0.003	0.0000018	0.039
19	Day	14.20-15.30	TMAW	0.000	0.031	0.000	4011.485	0.012	0.223	0.213	0.002	0.0000024	0.015
20	Day	14.20-15.30	TMAE	0.000	0.000	0.002	2538.997	0.014	0.290	0.257	0.003	0.0000031	0.000
21	Night	19.00-20.10	Director	0.000	0.012	0.007	240.183	0.009	0.134	0.121	0.003	0.0000014	0.011
22	Night	20.10-21.20	Director	0.000	0.084	0.000	240.183	0.017	0.161	0.113	0.004	0.0000017	0.039
				Average									
				0.006	0.072	0.029	2143.317	0.017	0.228	0.193	0.004	0.000	0.032

APPENDIX 7

Kuesioner NASA TLX

Kuesioner ini dibuat untuk mengetahui tingkat beban kerja pada pemandu Unit *Approach Control* (APP) di Perusahaan Umum Lembaga Penyelenggara Pelayanan Navigasi Penerbangan Indonesia (Perum LPPNPI) Kantor Cabang Surabaya atau yang lebih umum dikenal sebagai AirNav Juanda. Secara singkat, beban kerja merupakan usaha dan kemampuan yang harus diberikan untuk menyelesaikan tugas. Metode yang digunakan pada penelitian tugas akhir ini untuk mengukur beban kerja adalah NASA-*Task Load Index* (NASA-TLX).

Metode NASA-TLX merupakan metode pengukuran beban kerja, khususnya beban kerja mental, yang bersifat subjektif. Wujudnya berupa kuesioner yang dikembangkan untuk memudahkan pengukuran 6 indikaror beban kerja secara subjektif, namun tetap sensitif dan terukur. 6 indikator tersebut yaitu: 1) kebutuhan mental, 2) kebutuhan fisik, 3) kebutuhan waktu, 4) usaha, 5) performansi, dan 6) frustrasi. Penjelasan mengenai indikator-indikator tersebut terdapat pada halaman selanjutnya. Prosedur pengisian kuesioner ini terbagi menjadi 3 tahap yaitu: 1) pengisian biodata, 2) perbandingan tiap skala (*paired comparison*), dan 3) pemberian nilai (*rating*). Oleh karena itu, kami memohon kesediaan Bapak/Ibu untuk mengisi kuesioner ini sebagaimana petunjuk yang telah diberikan. Terimakasih atas partisipasi Bapak/Ibu.

Biodata Responden

Nama	**:**
Umur	**:**
Shift	**:**
Sektor	**:**
Lamanya bekerja di APP-Radar	**:**
Lamanya bekerja di *airspace* Juanda	**:**

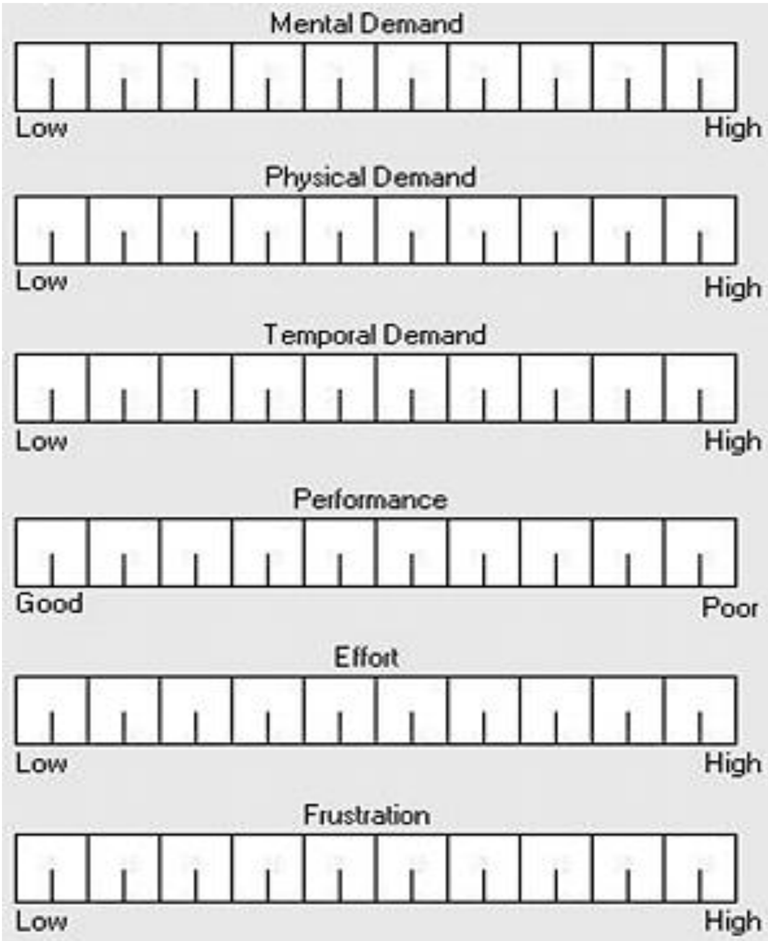
Tabel Penjelasan Indikator

Indikator	Tingkat	Keterangan	Contoh
Kebutuhan Mental (MD)	Rendah/ Tinggi	Seberapa besar aktivitas mental yang diperlukan untuk melihat, mengingat, dan mencari. Apakah pekerjaan tersebut mudah atau sulit, sederhana atau kompleks, memerlukan ketelitian atau tidak.	Berfikir, memutuskan, menghitung, mengingat, mencari, dsb.
Kebutuhan Fisik (PD)	Rendah/ Tinggi	Seberapa besar jumlah aktivitas fisik yang diperlukan.	Menarik, mengangkat, mendorong, dsb.
Kebutuhan Waktu (TD)	Rendah/ Tinggi	Seberapa besar Anda merasa pekerjaan saat ini dibatasi dalam jangka waktu tertentu untuk dilakukan. Apakah pekerjaan terasa perlahan dan santai atau cepat dan melelahkan.	
Performansi (OP)	Baik/ Kurang	Seberapa besar Anda telah menyelesaikan pekerjaan tersebut dengan baik dan seberapa puas Anda dengan hasilnya.	
Usaha (EF)	Rendah/ Tinggi	Seberapa besar Anda (mental atau fisik) yang diperlukan untuk menyelesaikan pekerjaan tersebut.	
Tingkat Frustasi (FR)	Rendah/ Tinggi	Seberapa besar rasa stress yang muncul dibandingkan dengan perasaan nyaman selama melakukan pekerjaan tersebut.	

<u>Pemberian Nilai</u>

Pada bagian ini, Anda diharapkan memberi nilai untuk tiap indicator yang ada. Cara pengerjaan:

1. Bacalah definisi 6 indikator penilaian yang terdapat pada tabel penjelasan indikator.
2. Terdapat dua titik ujung maksimum yang rentang nilainya dari 0-100. Ujung kiri adalah *low* sedangkan ujung kanan adalah *high*. Namun harap diperhatikan mengenai adanya perbedaan pada tingkat penilaian pada indikator performansi, yaitu ujung kiri adalah *good* sedangkan ujung kanan adalah *poor*.
3. Responden diharapkan memilih dengan cara memberi tanda silang (X) pada garis atau di atantara garis skala.



Perbandingan Tiap Skala

Pada bagian ini Anda diharapkan untuk memilih salah satu indikator pengukuran. Cara pengerjaan:

1. Bacalah definisi 6 indikator penilaian yang terdapat pada tabel penjelasan indikator.
2. Responden membandingkan manakah salah satu yang berkontribusi lebih besar pada saat Anda melakukan pekerjaan Anda (tidak ada benar maupun salah).
3. Pilihlah salah satu indikator yang lebih mencerminkan/dominan/diperlukan untuk melakukan pekerjaan Anda dengan cara memberi tanda centang (✔) pada kotak pilihan.

Frustrasi atau Usaha ☐ Frustrasi ☐ Usaha	Frustrasi atau Kebutuhan Mental: ☐ Frustrasi ☐ Kebutuhan Mental
Performansi atau Kebutuhan Mental: ☐ Performansi ☐ Kebutuhan Mental	Usaha atau Performansi: ☐ Usaha ☐ Performansi
Performansi atau Kebutuhan Waktu: ☐ Performansi ☐ Kebutuhan Waktu	Kebutuhan Waktu atau Frustrasi: ☐ Kebutuhan Waktu ☐ Frustrasi
Kebutuhan Mental atau Usaha: ☐ Kebutuhan Mental ☐ Usaha	Kebutuhan Waktu atau Usaha: ☐ Kebutuhan Waktu ☐ Usaha
Kebutuhan Mental atau Kebutuhan Fisik: ☐ Kebutuhan Mental ☐ Kebutuhan Fisik	Kebutuhan Fisik atau Frustrasi: ☐ Kebutuhan Fisik ☐ Frustasi

Usaha atau Kebutuhan Fisik: ☐ Usaha ☐ Kebutuhan Fisik	Performansi atau Frustrasi: ☐ Performansi ☐ Frustasi
Kebutuhan Fisik atau Kebutuhan Waktu: ☐ Kebutuhan Fisik ☐ Kebutuhan Waktu	Kebutuhan Fisik atau Performansi: ☐ Kebutuhan Fisik ☐ Performansi
Kebutuhan Waktu atau Kebutuhan Mental: ☐ Kebutuhan Waktu ☐ Kebutuhan Mental	

Terima kasih atas partisipasi dan bantuan Bapak/Ibu

APPENDIX 8

Detailed result of NASA-TLX assessment

No	Age (Years Old)	Experience		Scheduled for			Rating						Paired Comparison							MD	PD	TD	OP	EF	FR	Total	WWL	Workload Category
		APP Rating (Years)	Controlling for AirNav Juanda (Years)	Shift	Observation Time (GMT+7)	Sector	Mental Demand (MD)	Physical Demand (PD)	Temporal Demand (TD)	Per-formance (OP)	Effort (EF)	Frustra-tion (FR)	MD	PD	TD	OP	EF	FR	Total									
1	54	15	16	Day	15.30-17.20	Director	40	80	80	40	90	70	2	2	3	4	4	0	15	80	160	240	160	360	0	1000	66.66667	High
2	43	9	5	Day	15.30-17.20	TMAW	90	80	95	0	80	0	5	2	4	1	3	0	15	450	160	380	0	240	0	1230	82	Very-High
3	46	17	12	Day	15.30-17.20	TMAE	90	85	80	5	95	0	2	1	3	4	5	0	15	180	85	240	20	475	0	1000	66.66667	High
4	39	13	18	Morning	09.20-10.30	TMAW	80	70	90	30	80	80	2	2	3	2	5	1	15	160	140	270	60	400	80	1110	74	High
5	46	4	9	Morning	09.20-10.30	Director	80	70	75	20	85	50	4	3	2	4	2	0	15	320	210	150	80	170	0	930	62	High
6	[redacted]			Morning	09.20-10.30	TMAE	[redacted]																					
7	38	14	14	Morning	09.20-10.30	TMAW	90	90	95	5	95	25	4	5	3	1	2	0	15	360	450	285	5	190	0	1290	86	Very-High
8	37	3	4	Morning	09.20-10.30	TMAE	99	60	50	5	100	75	3	1	0	5	4	2	15	297	60	0	25	400	150	932	62.13333	High
9	47	15	15	Morning	09.20-10.30	Director	60	50	100	0	70	0	3	1	4	2	5	0	15	180	50	400	0	350	0	980	65.33333	High
10	54	12	12	Morning	11.40-13.00	Director	95	90	90	10	90	70	4	0	3	5	2	1	15	380	0	270	50	180	70	950	63.33333	High
11	51	14	4	Morning	11.40-13.00	TMAW	90	50	100	0	100	20	2	0	3	5	4	1	15	180	0	300	0	400	20	900	60	High
12	[redacted]			Morning	11.40-13.00	TMAE	[redacted]																					
13	47	18	6	Morning	08.10-09.20	TMAE	60	70	50	20	70	70	4	2	2	2	5	0	15	240	140	100	40	350	0	870	58	High
14	[redacted]			Morning	08.10-09.20	TMAW	[redacted]																					
15	57	30	30	Morning	08.10-09.20	Director	100	90	80	0	100	50	3	1	2	5	4	0	15	300	90	160	0	400	0	950	63.33333	High
16	38	9	3	Morning	10.30-11.40	TMAE	0	10	20	0	0	0	1	5	2	3	4	0	15	0	50	40	0	0	0	90	6	Low
17	37	4	7	Morning	10.30-11.40	Director	80	70	80	10	100	20	3	0	3	4	4	1	15	240	0	240	40	400	20	940	62.66667	High
18	[redacted]			Morning	10.30-11.40	TMAW	[redacted]																					
19	40	3	3	Day	13.00-14.10	TMAW	68	20	20	25	75	20	4	1	2	5	3	0	15	272	20	40	125	225	0	682	45.46667	Medium-High
20	47	3	3	Day	13.00-14.10	TMAE	50	30	40	20	80	60	3	1	5	3	3	0	15	150	30	200	60	240	0	680	45.33333	Medium-High
21	38	4	18	Day	13.00-14.10	Director	80	65	80	10	80	75	4	0	3	2	5	1	15	320	0	240	20	400	75	1055	70.33333	High
22	56	16	16	Night	19.00-20.30	West	55	55	45	65	45	65	4	1	3	5	2	0	15	220	55	135	325	90	0	825	55	High
23	59	20	38	Night	19.00-20.30	Director	80	70	70	10	80	80	4	1	2	3	5	0	15	320	70	140	30	400	0	960	64	High
24	51	16	16	Day	14.20-15.30	TMAW	90	60	98	6	91	92	2	1	4	4	4	0	15	180	60	392	24	364	0	1020	68	High
25	38	4	11	Day	14.20-15.30	TMAE	80	60	80	70	80	70	3	0	4	2	5	1	15	240	0	320	140	400	70	1170	78	High
26	24	1	1	Day	14.20-15.30	Director	50	50	50	25	80	40	3	1	2	5	4	0	15	150	50	100	125	320	0	745	49.66667	High
27	41	3	17	Night	19.00-20.10	Director	90	90	90	5	90	30	3	1	2	4	5	0	15	270	90	180	20	450	0	1010	67.33333	High
28	45	13	16	Night	20.10-21.20	All	85	35	75	25	85	80	4	1	2	5	3	0	15	340	35	150	125	255	0	905	60.33333	High
																											Medium-High	**9.1%**
																											High	**81.8%**
																											Very-High	**9.1%**

Note: The red number is eliminated because they are outlayers

Comparison between NASA-TLX WWL with DD_5 and DD_{10} values

Date	Round	APP Controller	Shift	Observation Time (UTC+7)	Sector	DD Complexity Factors										10 Factors	NASA-TLX	
						S5	NUMHORIZ	SCI	SV	C15	AC	WB PROX	C9	AD1	S10		WWL	Workload Category
2/5/2017	1	1	Day	15.30-16.20	Director	0.000	0.113	0.044	240.183	0.018	0.188	0.113	0.004	0.0000020	0.035	240.698	16.0465	High
		2	Day	15.30-16.20	TMAW	0.000	0.028	0.017	4011.485	0.011	0.208	0.159	0.003	0.0000022	0.009	4011.919	267.46	High
		3	Day	15.30-16.20	TMAE	0.000	0.000	0.003	2826.349	0.006	0.094	0.079	0.001	0.0000010	0.000	2826.532	188.44	High
3/5/2017	2	4	Morning	09.20-10.30	TMAW	0.000	0.082	0.000	4011.485	0.025	0.285	0.270	0.006	0.0000030	0.033	4012.186	267.479	High
		5	Morning	09.20-10.30	Director	0.000	0.117	0.096	240.183	0.019	0.285	0.243	0.005	0.0000030	0.051	240.999	16.07	High
4/5/2017	3	6	Morning	09.20-10.30	TMAW	0.000	0.070	0.000	4011.485	0.023	0.251	0.232	0.004	0.0000027	0.022	4012.087	267.472	Very High
		7	Morning	09.20-10.30	TMAE	0.000	0.035	0.000	2826.349	0.025	0.201	0.165	0.003	0.0000021	0.026	2826.804	188.454	High
		8	Morning	09.20-10.30	Director	0.052	0.258	0.106	240.183	0.030	0.391	0.320	0.017	0.0000042	0.095	241.452	16.10	High
4/5/2017	4	9	Morning	11.40-13.00	Director	0.000	0.156	0.108	240.183	0.026	0.290	0.279	0.006	0.0000031	0.068	241.117	16.0745	High
		10	Morning	11.40-13.00	TMAW	0.000	0.047	0.000	4011.485	0.022	0.276	0.184	0.003	0.0000029	0.039	4012.055	267.47	High
5/5/2017	5	11	Morning	08.10-09.20	TMAE	0.000	0.000	0.000	2826.349	0.011	0.140	0.096	0.002	0.0000015	0.000	2826.598	188.44	High
		12	Morning	08.10-09.21	Director	0.000	0.090	0.025	240.183	0.026	0.195	0.126	0.004	0.0000021	0.028	240.676	16	High
5/5/2017	6	13	Morning	10.30-11.40	Director	0.085	0.128	0.115	240.183	0.015	0.280	0.265	0.010	0.0000030	0.068	241.149	16.08	High
5/5/2017	7	14	Day	13.00-14.10	TMAW	0.000	0.000	0.000	4011.485	0.009	0.097	0.088	0.000	0.0000010	0.000	4011.679	267.445	High
		15	Day	13.00-14.10	TMAE	0.000	0.078	0.000	2826.349	0.022	0.283	0.265	0.004	0.0000030	0.024	2827.025	188.47	High
		16	Day	13.00-14.10	Director	0.000	0.156	0.111	240.183	0.011	0.253	0.235	0.004	0.0000027	0.058	241.013	16.07	High
6/5/2017	8	17	Night	19.00-20.10	TMAW&E	0.000	0.014	0.000	6837.834	0.014	0.328	0.258	0.004	0.0000035	0.053	6838.505	455.9	Very High
		18	Night	19.00-20.10	Director	0.000	0.084	0.013	240.183	0.011	0.168	0.165	0.003	0.0000018	0.039	240.667	16.04	High
10/5/2017	9	19	Day	14.20-15.30	TMAW	0.000	0.031	0.000	4011.485	0.012	0.223	0.213	0.002	0.0000024	0.015	4011.981	267.47	High
		20	Day	14.20-15.30	TMAE	0.000	0.000	0.002	2538.997	0.014	0.290	0.257	0.003	0.0000031	0.000	2539.564	169.304	High
29/5/2017	10	21	Night	19.00-20.10	Director	0.000	0.012	0.007	240.183	0.009	0.134	0.121	0.003	0.0000014	0.011	240.480	16.03	Medium-High
29/5/2017	11	22	Night	20.10-21.20	Director	0.000	0.084	0.000	240.183	0.017	0.161	0.113	0.004	0.0000017	0.039	240.601	16.04	Medium-High

BIOGRAPHY

Nita Inas Sakinah (Nita) was born in Surabaya, 30th October 1994. She was growth, lived and formal educated in Surabaya with her parents and one elder brother. The formal education she graduated were TK Muhajirin in 2001, SD Muhammadiyah 4 in 2007, SMPN 1 in 2010 and SMAN 5 in 2013. After graduated from senior high school, she enrolled study in Industrial Engineering Department of Sepuluh Nopember Institute of Technology. Moreover, she will be graduated from college on September 2017.

During college, Nita was active in several academic in non-academic activities. She took several software trainings such as AutoCAD, Fusion 360, Sketch Up, Catia, Lingo, Ms Excel Solver, Minitab and Arena. She also took some other training which are scientific paper writing, business model canvas and basic level of student self-reliance and management training (LKMM TD). As a vibrant student, she was encouraged by several competitions and gained some achievements: 1) 3rd winner of National Debate and Essay Competition by Syiah Kuala University Aceh, 2) Finalist in ASEAN Product Design Competition INDISCO by Diponegoro University Semarang, and 3) Finalist in ASEAN Product Design Competition CHRONICS by Gadjah Mada University Yogyakarta. Furthermore, she had experience in student exchange program to UTeM Malacca in her third semester, 2014. In her sophomore year, she also selected in ASEAN Young Engineering and Scientist (YES) Summit and considered as best presenter for transportation cluster. After that, her interest in international friendship and professional environment became more expressed; she took role in International Relation and Partnership Team in AIESEC Local Committee Surabaya. In her third year, she was selected to be one of researchers in Sustainable Island Development Initiatives (SIDI) Student Research and Development Team (SR&DT) toward Maratua Island sustainability in East

Borneo. Each batch of this research was conducted for a semester between academics from ITS and Wismar University which supported by Indonesia Ministry of Tourism and German Academic Exchange Service (DAAD). In the same time until the last semester of college phase, she became a Laboratory Assistant of Ergonomic and Work System Design. The last but not least, she experienced an internship program in PT Angkasa Pura I Juanda International Airport which leaded her final project concerned to its separated company, AirNav Juanda. Furthermore, the AirNav Juanda APP Controller workload measurement became her research topic and study case.

Through some experiences, her soft and hard skills are sharpened. She has interest to pursue career related in workforce planning, risk analysis and business strategy. For any occasions or requirements, she can be contacted via e-mail nitainassakinah@gmail.com.